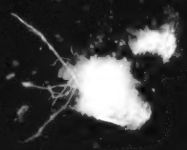
CANMET

SURVEILLANCE MICROSISMIQUE DANS LES MINES DU CANADA



PROCEEDINGS OF A CANMET-SPONSORED WORKSHOP

ACTES D'UN ATELIER PARRAINÉ PAR LE CANMET

Canada

MICROSEISMIC MONITORING IN CANADIAN MINES

SURVEILLANCE MICROSISMIQUE DANS LES MINES DU CANADA

PROCEEDINGS OF A CANMET-SPONSORED WORKSHOP

Sudbury, Ontario
August, 1984

ACTES D'UN ATELIER PARRAINÉ PAR LE CANMET

Sudbury (Ontario)
août, 1984

Minerals Research Program
Mining Research Laboratories
Divisional Report MRP/MRL 85-23

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MICROSEISMIC MONITORING IN CANADIAN MINES

Proceedings of a CANMET sponsored Workshop held in Sudbury, Ontario 14th-15th August, 1984

The Canada Centre for Mineral and Energy Technology (CANMET) sponsored a workshop in August, 1984, to cover various aspects of microseismic monitoring in Canadian mines. Representatives from organizations throughout Canada participated. Twelve papers were presented for discussion.

Presentations were made on multichannel microseismic systems, high-frequency microseismic monitors, and potential applications for microseismic techniques.

SURVEILLANCE MICROSISMIQUE DANS LES MINES DU CANADA

Actes d'un atelier parrainé par le CANMET tenu à Sudbury (Ontario) les 14 et 15 août 1984

Le Centre canadien de la technologie des minéraux et de l'énergie (CANMET) a parrainé un atelier en août 1984 qui portait sur les différents aspects de la surveillance microsismique dans les mines du Canada. Des représentants de différents organismes de tout le Canada y ont présenté douze communications qui par la suite ont été débattues.

Ces communications ont traité de systèmes microsismiques à plusieurs voies, de moniteurs microsismiques hautes fréquences et des applications possibles des techniques microsismiques.

85-34097

FOREWORD

This publication is the proceedings of a workshop sponsored by CANMET, entitled "Microseismic Monitoring in Canadian Mines", that was held in Sudbury, August 14-15th, 1984.

Participants included representatives of the mining industry, universities, provincial ministries, CANMET and private consultants. Lists of the participants and their organizations are included.

The workshop was split into three general sessions. One session dealt with mines using multichannel microseismic monitoring systems; one with results from high frequency microseismic monitors; in the other, presentations were made by organizations concerned with stability problems. The papers are grouped to reflect these sessions.

The assistance of INCO Ltd. in providing the opportunity for a visit to Creighton Mine to observe a microseismic monitoring system in operation is acknowledged.

Paul MacDonald

October, 1984

AVANT-PROPOS

La présente publication constitue les actes de l'atelier parrainé par le CANMET, "Surveillance microsismique dans les mines du Canada", tenu à Sudbury les 14 et 15 août 1984.

Y ont participé des experts-conseils privés ainsi que des représentants de l'industrie minière, d'universités, de ministères provinciaux et du CANMET. La liste des participants et de leurs organismes est donnée plus loin.

L'atelier a été divisé en trois séances générales: les mines utilisant des systèmes de surveillance microsismique à plusieurs voies, les résultats obtenus de moniteurs microsismiques hautes fréquences et les présentations d'organismes qui s'intéressent aux problèmes de stabilité. Les communications sont groupées par séance.

Nous remercions L'INCO Ltd. qui nous a permis de visiter la mine Creighton où nous avons pu observer un système de surveillance microsismique en exploitation.

Paul MacDonald

Octobre 1984

85-3409/

COMPANIES AND ORGANIZATIONS REPRESENTED AT THE WORKSHOP

Algoma Steel Corporation Ltd.

Campbell Red Lake Mines Ltd.

CANMET, Energy, Mines and Resources Canada

Denison Mines Ltd.

Dickenson Mines Ltd.

Electro Lab, Washington, USA

Falconbridge Ltd.

Inco Ltd.

Kidd Creek Mines Ltd.

Lac Minerals Ltd.

Laurentian University, Sudbury

McGill University, Montreal

New Brunswick – Department of Natural Resources

Noranda Research Centre, Pointe Claire, Quebec

Ontario – Ministry of Labour

Rio Algom Ltd.

Roctest Ltd., St. Lambert, Quebec

Steffen, Robertson and Kirsten, (B.C.) Inc.

University of British Columbia, Vancouver

SOCIÉTÉS ET ORGANISMES REPRÉSENTÉS À L'ATELIER

Algoma Steel Corporation Ltd.

Campbell Red Lake Mines Ltd.

CANMET, Énergie, Mines et Ressources Canada

Denison Mines Ltd.

Dickenson Mines Ltd.

Electro Lab, Washington, É.-U.

Falconbridge Ltd.

Inco Ltd.

Kidd Creek Mines Ltd.

Lac Minerais Ltée

Université Laurentienne, Sudbury

Université McGill, Montréal

Nouveau-Brunswick – Ministère des Richesses naturelles

Centre de recherches Noranda, Pointe-Claire, Québec

Ontario – Ministère du Travail

Rio Algom Ltd.

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Steffen, Robertson & Kirsten (C.-B.) Inc.

Université de la Colombie-Britannique, Vancouver

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OPENING REMARKS

J. Udd

The role of CANMET in microseismic monitoring is relatively new. Our activity was started about two years ago by Dr. David Hedley at the Elliot Lake Laboratory. During the subsequent period we have become more familiar with what is happening in terms of the use of monitoring systems in mines across the country, and we have become more sensitive to the fact that there is a collectivity of opinion among operators regarding operational problems. Early in the spring, before I joined CANMET, Paul MacDonald suggested that there should be a workshop in which specialists who had *hands-on* experience with microseismic systems could discuss the problems they face and the methods they employed to overcome them. The aim of the workshop would be to determine if problems are "site-specific' or if there could be a collective opinion on areas of difficulty in microseismic monitoring.

Subsequent to that time, because of the tragic accident at Falconbridge and a rockburst situation at Inco's Creighton Mine, there has been a focussing of interest and a much heightened awareness of the subject. Nevertheless, in spite of the sharpened interest caused by recent events, the original objectives for the workshop remain. These are: to sit down together to discuss our problems; to share these with each other; to try to transfer information back and forth; and to try to identify some areas in which we believe future work should be directed. That is what we are particularly hoping to achieve by convening this workshop.

As the number of workshop participants has grown – because of recent events – it has become evident that both the participants and their organizations have been looking toward the production of a set of formal notes as a result of the discussions. With that in mind, it is our intention to issue a CANMET report as quickly as possible after the conclusion of the workshop. The document will contain the communications that have been given to us in written form, together with our own notes and contributions.

DISCOURS D'OUVERTURE

J. Udd

Le rôle du CANMET dans la surveillance microsismique est relativement nouveau. Les travaux dans le domaine ont été lancés il y a environ deux ans par M. David Hedley, D.Sc. au laboratoire d'Elliot Lake. Plus tard, nous avons commencé à nous familiariser avec les systèmes de surveillance utilisés dans les mines, dans tout le pays, et nous sommes devenus plus sensibles au fait qu'il existe un consensus parmi les opérateurs en ce qui concerne les problèmes de fonctionnement. Au début du printemps, avant que je ne me joigne au CANMET, Paul MacDonald avait proposé de réunir un petit atelier devant permettre aux spécialistes ayant une expérience pratique des systèmes microsismiques de discuter des difficultés éprouvées et des méthodes utilisées pour les surmonter. Notre objectif était de déterminer si ces difficultés étaient propres aux emplacements ou s'il était possible de les généraliser.

Par la suite, l'accident tragique de Falconbridge et les coups de charge survenus dans la mine Creighton de l'Inco ont ravivé l'intérêt et considérablement attiré l'attention sur le sujet. Nous n'avons néanmoins pas modifié les objectifs de l'atelier, qui demeuraient: se réunir pour discuter de nos difficultés, partager nos connaissances avec d'autres, essayer d'échanger de l'information dans les deux sens, et essayer de répérer certains domaines vers lesquels orienter nos travaux.

Les récents événements ayant donné de l'ampleur à l'atelier, les participants et leurs organismes souhaitaient manifestement disposer d'un quelconque compte rendu officiel des débats. Aussi notre intention est de publier un rapport de CANMET aussi rapidement que possible après la tenue de l'atelier. Ce rapport contiendra les communications présentées par écrit ainsi que nos propres observations et contributions.

MICROSEISMIC MONITORING AT FALCONBRIDGE MINE

FALCONBRIDGE, ONTARIO

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April 1984

ABSTRACT

Falconbridge Mine has a history of significant microseismic activity dating back to 1955. Since mid 1981, a microseismic monitoring system has been operating in the area around the No. 9 Shaft hoist room, located 25 metres from the ore zone at a depth of 1200 metres. Several mine-wide faults dissect this area and have been shown to be microseismic active due to mining. The microseismic monitor has been interfaced with a small dedicated personal computer and a communications device to perform routine data evaluation and to produce graphic output. The programs are described and selected results from the monitoring program are presented.

**Formerly Geomechanics Supervisor*

SURVEILLANCE MICROSISMIQUE À LA MINE DE LA FALCONBRIDGE

FALCONBRIDGE (ONTARIO)

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Avril 1984

RÉSUMÉ

L'agitation microsismique est importante à la mine de la Falconbridge depuis 1955. Au milieu de 1981, un système de surveillance microsismique a été installé au voisinage de la salle de la machine d'extraction nº 9, située à 25 m de la zone minéralisée, à 1200 m de profondeur. Plusieurs failles béantes rencontrées dans la mine traversent cette région et sont le centre d'une agitation sismique causée par l'exploitation minière. Le moniteur microsismique est relié à un petit ordinateur personnel spécialisé et à un dispositif de communications servant à l'évaluation des données et à la production de graphiques. Nous décrivons les programmes et nous présentons des résultats provenant du programme de surveillance.

**Anciennement surveillant de la géomécanique*

MICROSEISMIC MONITORING AT FALCONBRIDGE MINE

INTRODUCTION

Falconbridge Mine is located on the southeast rim of the Sudbury Basin. The nickel-copper sulphide ore zone is essentially a tabular ore body striking approximately east-west and dipping at 80 north near surface and rolling to 75 to 80 south by the 1000 level. (Mine level numbers represent the approximate depth in feet below ground surface). This dip is maintained down to the 6000 level. The north wall is comprised of jointed norite, and a faulted contact up to 1 m thick exists between the ore zone and the norite. The south wall rock is a greenstone with highly silicious lenses and often has a faulted contact with the ore zone. No less than five mine wide faults exist, (Fig. 1.1).

Mining has been carried out from virtually the bedrock contact to depths of 1830 m, although the majority of current activity is between 900 and 1500 m below surface. A winze provides access below the 4025 level and the cage hoist room is located on the 3850 level in the north wall, 25 m from the contact. Because of concern for the stability of this hoist room, there has been no mining activity within 60 m of the hoist room and by 1980 this block of ore was one of the major blocks of high grade ore remaining in the mine. Mining of this block was originally scheduled for very late in the decade.

Prior to a six month shutdown in 1982, this mine produced approximately 450 000 t of ore annually, mainly by cut and fill techniques. Following the shutdown, annual production has been reduced to approximately 200 000 t. Production is now mainly by undercut and fill techniques.

Mining-induced seismicity has occurred at Falconbridge Mine since at least 1955 and reviews of the microseismic problems for the periods from 1965-1970 and from 1971-1979 were made by Singh (1) and Vongpaisal et al (2), respectively. The need for instrumentation was addressed by these authors. Following several large events during the spring of 1980, a decision was made to investigate existing microseismic monitors and to apply microseismic monitoring techniques in Falconbridge Mine. Application of microseismic monitoring to Falconbridge Mine was to concentrate upon the No. 9 Shaft hoist room area of the mine, particularly around the 4025 level where a large mechanized cut and fill stope was approaching this level. By mid 1981, the microseismic monitor was fully installed and within a year, a short period seismograph and a personal computer had been added to the system.

OBJECTIVES

The monitoring system had to be able to provide continuous and automatic recording of calendar time, approximate location, and estimated size of each microseismic event registered by the system. Because of the relatively limited experience with this type of microseismic monitoring in mining applications in North America in 1980, it was decided to evaluate the monitoring system's potential by a field trial. Expansion of the system would be carried out when the application results proved to be favourable. A short period seismograph to assist in the data interpretation and a small computer were to be obtained shortly after the system was operating satisfactorily.

Interpreted information from the microseismic monitor was to be used by ground control and operating personnel at the mine in order to minimize hazardous microseismic activity by means of more advanced long-term planning. This preventive approach is different to the approach where only precise prediction of events is required. If more informed long-term planning could be made, the problems associated with mining-induced microseismic activity might be minimized and any necessary remedial action could be implemented and evaluated ***before*** the onset of major problems.

SYSTEM DESCRIPTION

A thirty-two channel model 250 MP microseismic monitor with a single axis integrator was obtained from Electro-Lab of Spokane, Washington. A description of the various types of microseismic monitors may be found in Blake (3). MacDonald (4) gave a concise description of the model 250 MP monitor hardware in a

similar installation. Only eight geophones were obtained for the initial work because of the relatively small area to be monitored. Seven of the eight model 11SB geophones were mounted at the toes of 1.5 m long holes drilled vertically in the backs of existing mine openings and the hole collars were packed with sponge foam. This installation procedure was intended to minimize noise problems. The eighth sensor consisted of the sensing element of a model 11SB geophone, which had been mounted in an acrylic rod, with a mercury switch for orientation.

The rod was cement grouted at the toe of a 45 m diamond drill hole. A model 283 pre-amplifier, located at the hole collar, was connected to this sensor. This experimental sensor was to be used to develop a reliable method for down-hole sensor placement. By not limiting locations to mine openings, future sensor locations could be more flexible. Belden 8723 cable was used for any single geophone cable runs and for the multiple runs, a suitable size of multiple, foil wrapped, twisted pair cable was used. In particularly wet or severe conditions, a neoprene jacketed armoured version of the above cables was used. Figure 1.2 is an isometric view of the monitored area showing the original sensor locations.

The main control panel was repackaged in a robust four-door steel cabinet to provide additional physical protection and space for several modifications. Because of the quality of the 120 VAC 60 Hz power supply in the hoist room, a line filter was added to protect the unit. A battery backup power supply was also constructed and added so that the microseismic monitor would remain in operation during an underground power failure. Fused terminal blocks were added to protect the geophones and the panel components from stray voltages in the event of broken geophone cables. Because the teletype printer and computer are located approximately 1.5 km from the control panel, two modems were required. Communication is at 1200 baud on a dedicated line in the shaft phone cable. One of these modems and the panel were modified to permit resetting of the control panel from surface. The location of the control panel in the back of the No. 9 Shaft conventional hoist room provided reasonable security, and vandalism has never been a problem.

A DEC VT180 personal computer was connected to the microseismic monitor via a communications storage device. The VT180 computer is based upon a Z80 microprocessor and has a 64 Kbyte RAM, a monochrome screen, two 5.25 inch single sided, single density floppy diskette drives, and operates under the CP/M operating system. A DEC LA34 dot matrix printer is used to provide hard copies of the computer output.

In order to effectively store the data, a Sykes Comm-Stor II is used between the VT180 computer and the 250 MP monitor. This fully programmable 4 Kbyte RAM communications device allows data entry, storage, retrieval, editing and communication. Two 8-inch floppy diskette drives provide 233 Kbytes of usable storage on each drive. This unit runs in parallel with the teletype printer of the 250 MP monitor which is now used to provide a paper backup copy. Each event is stored as a discrete file with an automatically incremented numeric file name. The small 'y' in the calendar date output by the 250 MP monitor is used as the end of file character. Upon receiving a small 'y', an internal command program causes the file name number to be incremented and a new file to be opened with this name. All fill characters in the transmission from the 250 MP monitor are ignored.

Because the equipment capabilities do not allow multi-tasking operation, the communications line between the Comm-Stor II and the 250 MP control panel must be broken manually by means of a toggle switch. This permits the VT180 computer access to the data stored by the Comm-Stor II and simultaneously causes any new event to be stored in the internal buffer of the 250 MP control panel. Approximately 100 to 150 events may be stored in this buffer before data loss occurs. After the raw data is reviewed by programs run on the VT180 computer, the toggle switch must be reset to restore communication between the Comm-Stor II and the 250 MP control panel.

Additionally, a Teledyne Geotech Portacorder and a model S-500 short period seismometer were installed to compliment the microseismic monitor. This unit provides an independent partial backup system for the microseismic monitor as well as a means to identify recorded events which are related to blasting or seismic activity in adjacent mines. A conceptual arrangement of both systems is shown in Fig. 1.3.

DATA EVALUATION

As with any monitoring program, the most important step is the interpretation of the event data and not simply the data accumulation. However, unlike most other types of monitoring systems, the data presented by the 250 MP monitor has already been partially processed and these processes should be thoroughly reviewed by operators in order to allow proper event data evaluation.

The mathematics used in the event location routine, MacDonald (1983), are sensitive to the sensor array configuration and to the difference between the arrival times at the geophones. An evaluation may be made for any given sensor array by a simple program that calculates the geophone arrival times for a given theoretical event location. These times are substituted into the event location algorithm producing the same output given by the 250 MP monitor. Even for these theoretical solutions, a wide scatter in the calculated event locations is possible. Further evaluation of these calculated locations is very often necessary. Obviously, the variability of the in situ seismic velocity will tend to compound the location errors.

The single axis integrator of the 250 MP monitor integrates the voltage output from the geophone connected to the integrator whereas the triaxial integrator uses the square of the voltage. The numerical value produced by the integrator is taken to be a reflection of the energy released by the event. The triaxial integrator value more closely represents the energy released because it has no directional sensitivity and it produces an output signal which is more correctly associated with event energy.

The integrator accumulator is reset to zero when any geophone is triggered and the system waits for four or more subsequent arrivals to be registered before the event is processed by the monitor. Theoretically, the integrator should remain at zero until the sensor that is connected to the integrator is triggered and the ground velocity signal from this sensor will continue to be integrated until the event window time is reached. This energy number is, therefore, dependent on the duration of the integration period which may be any fraction of the preset event window. In the worst case, the sensor connected to the integrator may not register the event at all.

DATA EVALUATION PROGRAMS

Computer programs were written in BASIC to evaluate the raw data stored by the Comm-Stor II, to produce numerically contoured output of event locations, and to produce a wide variety of histograms.

Event evaluation is performed by a program, called MSMP4, which accesses a specified range of event files in the Comm-Stor II and converts the appropriate string values into numeric values. The event data is then checked by several validation processes. Experience with the 250 MP system has indicated that a minimum finite time period normally exists between any two valid events. The inter-event time is checked against this limit and the event is accepted or rejected. Subsequently, by using the individual calculated event locations, the arrival sequence at the geophones is checked. Attempts were made to check each arrival time against both a real time limit and percentage limit for theoretically produced events. Because so few of these events would be accepted by this method, this portion of the program was removed. Locations which produce the correct arrival sequence are accepted as being correct. If multiple locations for a single event have been accepted, these locations are used to define a best fit sphere. The centre of this sphere is taken to be the event location. This centre point is then used to adjust the event size, the En value, for the distance from the event to the integration sensor in order to estimate the En value at the source. Also, as described previously, an adjustment is made to account for the variable period of integration used to produce the En value. The pertinent event data values and the adjusted values are written into a file on a VT180 diskette containing *refined* events. It is this file which is used for further data processing or addition of more events. A flow chart of the principal steps in the program is given in Fig. 1.4.

The programming attempted to cover all the special cases which may develop during data analysis. It cannot, however, provide any subjective review of the events and it will, therefore, accept some invalid events and blasting. Experience has shown that relatively few of these events are accepted.

Program MSPLT1 uses the evaluated event data file produced by the program MSMP4 and produces numerically contoured event locations and/or a file which may be used for subsequent updating runs. Event data may be subjected to upper and lower limits on parameters including coordinate values, day, time, and event sizes. Output of the numerically contoured event locations is on pre-selected plan views, cross sectional views and longitudinal views corresponding to standard mine prints. A transparent overlay of the geology and mine openings is required because of the relatively complex geology and system of mine openings, and the limited capabilities of the VT180 computer. Figure 1.5 is a drafted example of the output with the openings and geology added.

In order to provide more flexibility in the event location contouring capabilities, a more general version of MSPLT1 was written, which allows the user to numerically contour event locations in any volume at any scale on each of the coordinate axes. This increased flexibility allows the user to plot views in plan, cross section,

and longitudinal section at either very large or very small scales. As with MSPLT1, updating of the contour plot file can be performed. Figure 1.6 is a drafted example of the output produced by this program.

Histograms of the data contained in the files produced by program MSMP4 are created by program MSBAR1. There is a wide selection of bar chart types which may be selected by specifying any one of five variables for one axis and any one of nine variables for the other axis. Data may be subjected to upper and lower limits on up to eight parameters. For example, a bar chart of the number of daily events versus day of the year subject to constraint on the time of the event and the x, y, and z coordinates of the event could be produced. Figure 1.7 is a drafted example of a more general type of chart. Automatic scaling of the horizontal axis is incorporated into the program as is the provision for subsequent updating or extension of the bar chart.

RESULTS AND CONCLUSIONS OF THE MONITORING PROGRAM

The microseismic monitoring system at Falconbridge Mine has been used to effectively monitor in three dimensions the response of the rock mass to mining activity and to establish general trends which may indicate an increasing likelihood for a major event to occur. These trends are by no means conclusive proof that such an event will occur and in one particular instance, there was no anomalous behaviour before an unusual large major event. The cost of installing a microseismic monitoring system makes it essential to obtain the maximum amount of information from the data. In this regard, the emphasis must be placed on an ongoing program of event data interpretation so as to recognize deviation from established patterns and to allow time to perform the appropriate remedial action.

In the early stages of event interpretation, it became clear that the existing faulting within the mine, especially in the north wall, played a key role in the location of a substantial number of the events. In the past, the highly siliceous lenses in the south wall had been assumed to be the source of the major events. Consequently, a review of the structural geology with emphasis on the faulting was performed and has correlated very well with the microseismic activity and past ground problems. This improved geological knowledge has permitted better planning of the mining in the hoist room area which is now in progress.

The senior operating personnel at the mine have found the interpreted event data to be useful not only in planning but also in providing them with information on the response of the mine rocks to mining activity. When large events have occurred, the event location provided by the monitor has assisted them in more rapid appraisal of any damage. The seismograph traces have been used to successfully convey the size of the events in visual terms.

Microseismic activity is not restricted to the immediate ore zone and in fact extends about 100 m into the walls from the ore zone contacts and for significantly greater distances along the faulting, (Fig. 6). Although these locations are outside the sensor array, their repeated occurrence indicates that activity is occurring in these areas.

In one trial, it was possible to monitor the effectiveness of de-stress blasting with the microseismic monitor by observing the shifting of event locations after the blast. A "y' intersection on the 4025 level began to produce an unusually large number of events over a period of several months. A small de-stress blast in the area was detonated and the microseismic activity shifted to adjacent areas.

The experimental geophone, which was mounted at the toe of a 45-m diamond drill hole, has performed effectively. It is proposed to use this type of installation in the future expansion of the system in order to instrument a larger volume than would otherwise be possible if sensor locations were limited to mine openings.

The only realistic method of installing a microseismic monitor is with some sort of computer capability. The volumes of data that can easily be generated require this type of processing to efficiently manipulate the data. In the initial stages of operation, sufficient time will be available to learn the manual methods of evaluation and their limitations.

PRESENT WORK

As a result of the economic conditions, minimal improvements have been made to the system since early 1982. However, commencement of mining activity in the hoist room area of the mine requires additional sensors and the relocation of several existing sensors. It is proposed to use a total of 15 geophones to cover an area from the 2975 level to the 4375 level, with the same east-west and north-south extent as the current array. Also, a triaxial square law integrator will be obtained to provide more realistic values for the estimate of event energy.

Falconbridge will be maintaining an ongoing effort to extend the application of microseismic monitoring within Falconbridge Mine and at other company mines that require similar systems.

ACKNOWLEDGEMENTS

The author would like to recognize the contributions of the various departments within Sudbury Operations who assisted in the installation of the microseismic system and, particularly, S.W. Lee of the Central Instrumentation Shop who provided the extensive electronics backup for the project.

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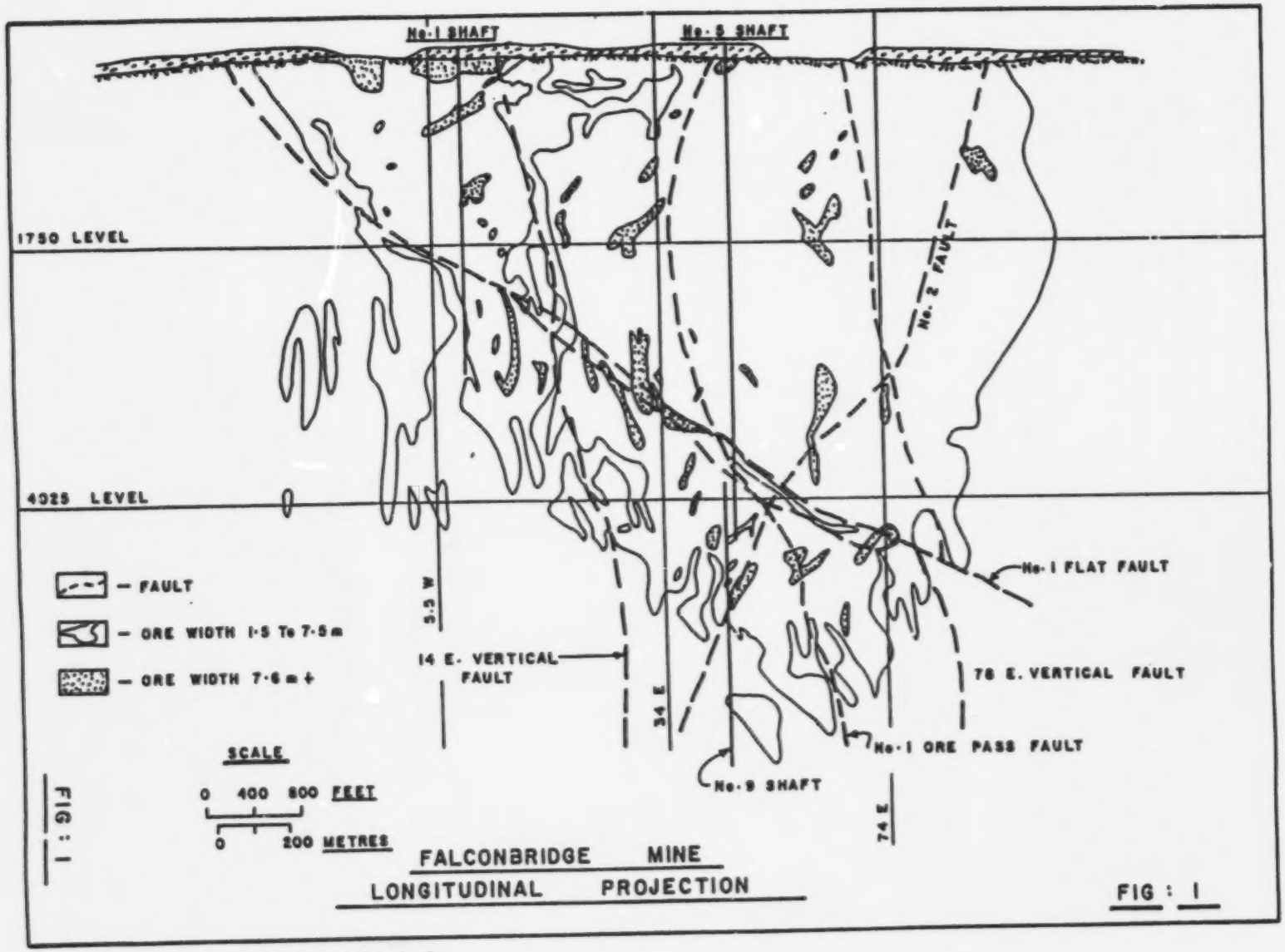

Fig. 1.1 — Falconbridge Mine longitudinal projection

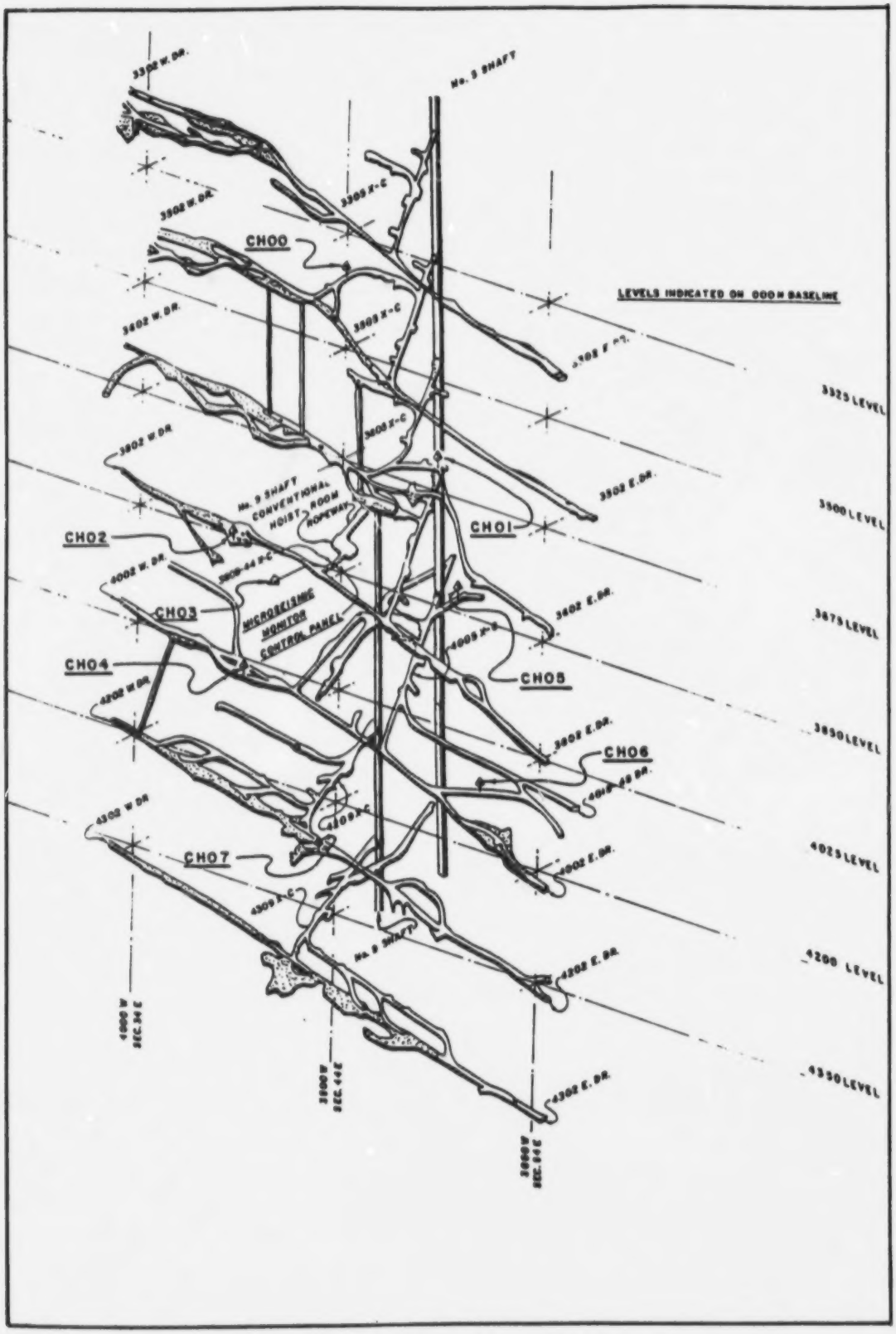

Fig. 1.2 — Falconbridge Mine isometric microseismic monitor sensor locations

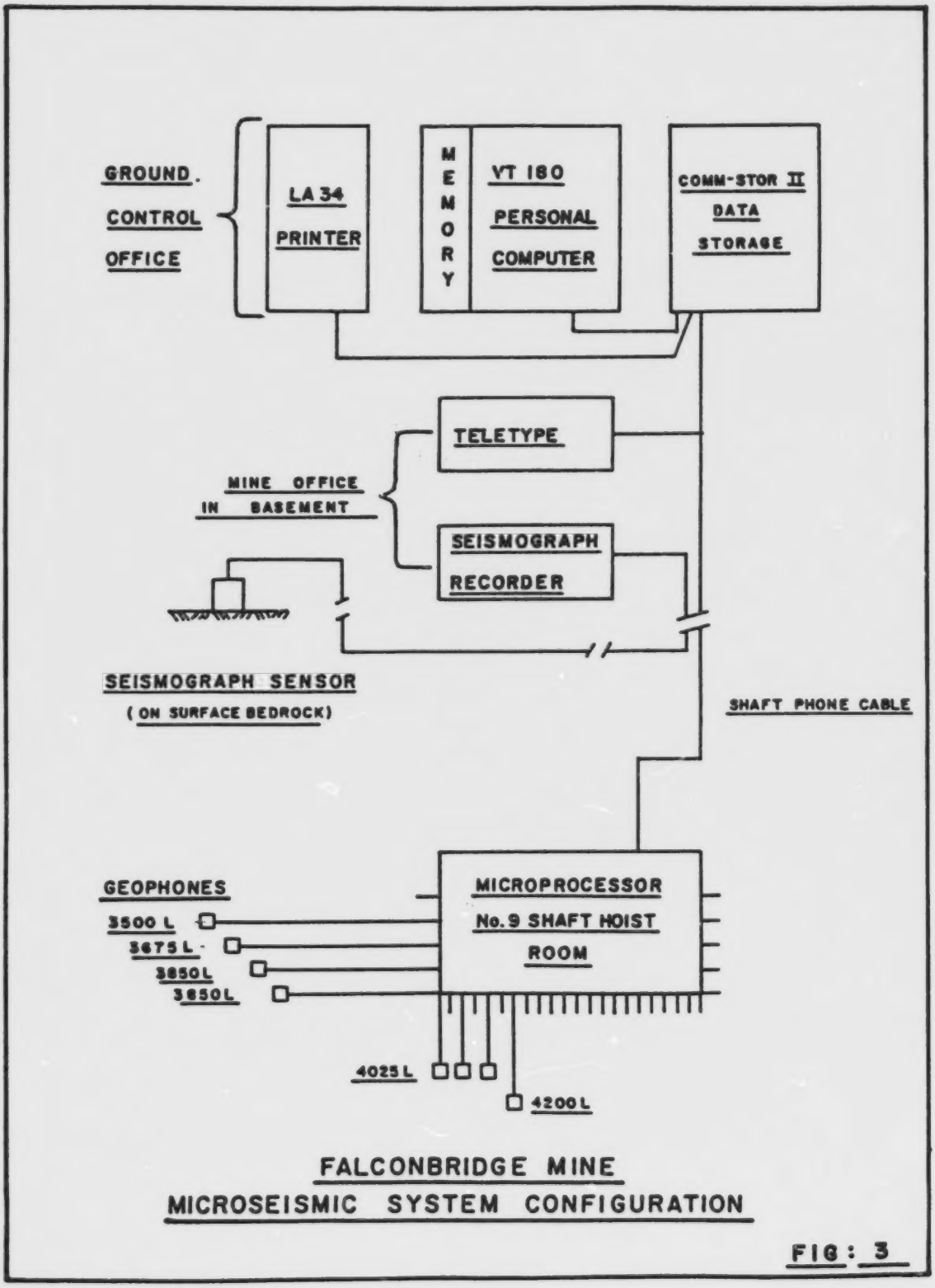

Fig. 1.3 — Falconbridge Mine microseismic system configuration

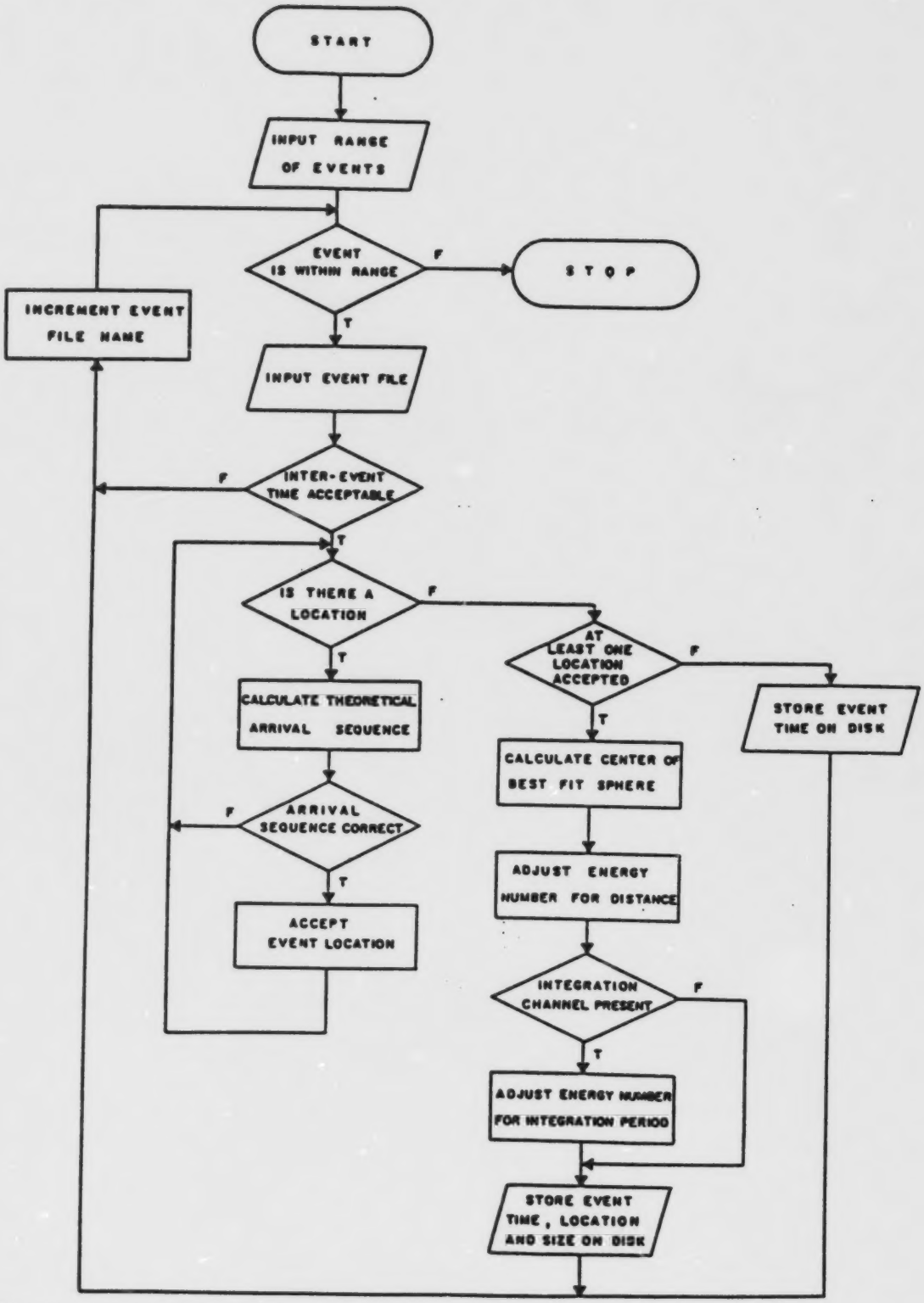

Fig. 1.4 — Conceptual flow chart for event evaluation

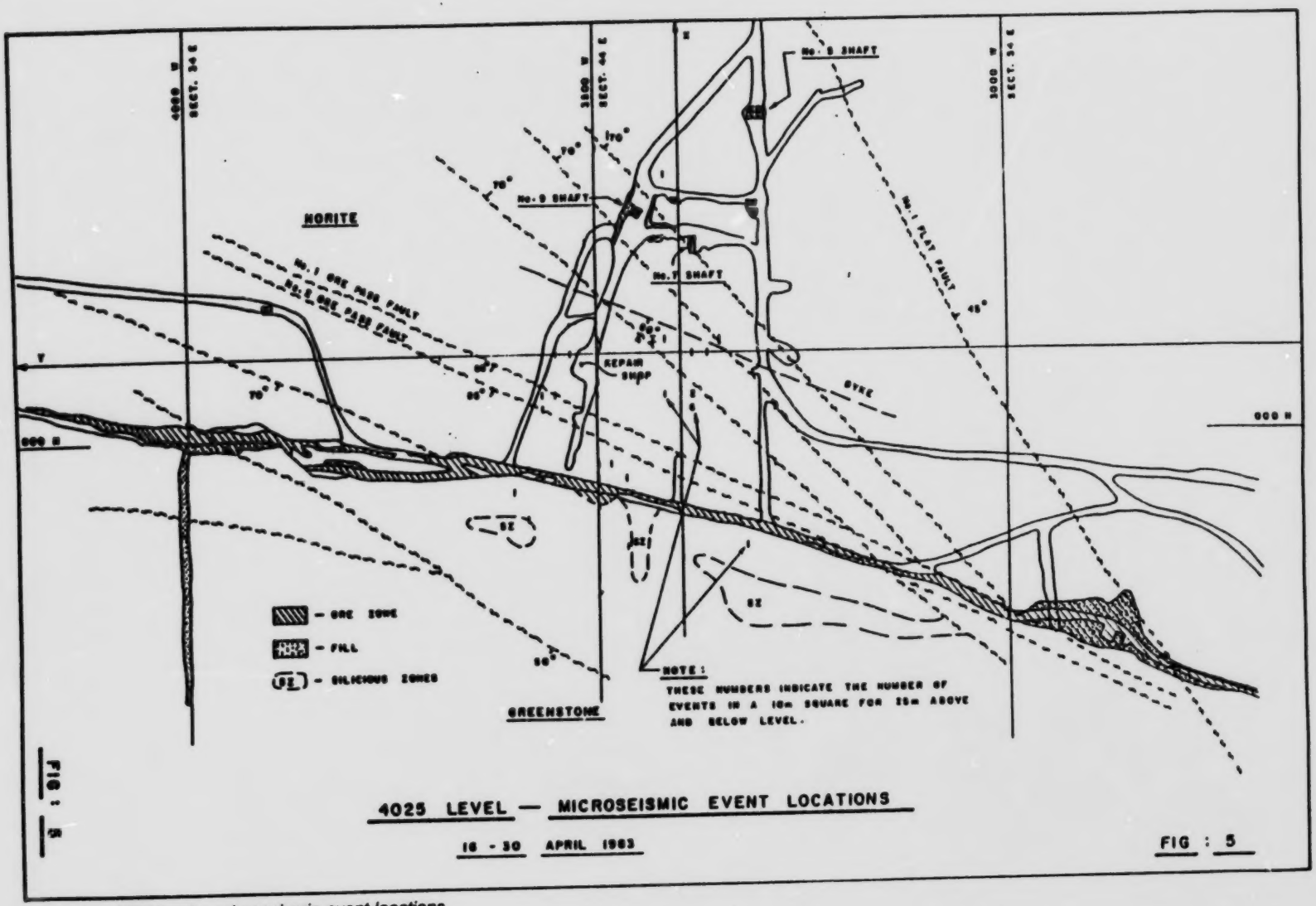

Fig. 1.5 — 4025 level – microseismic event locations

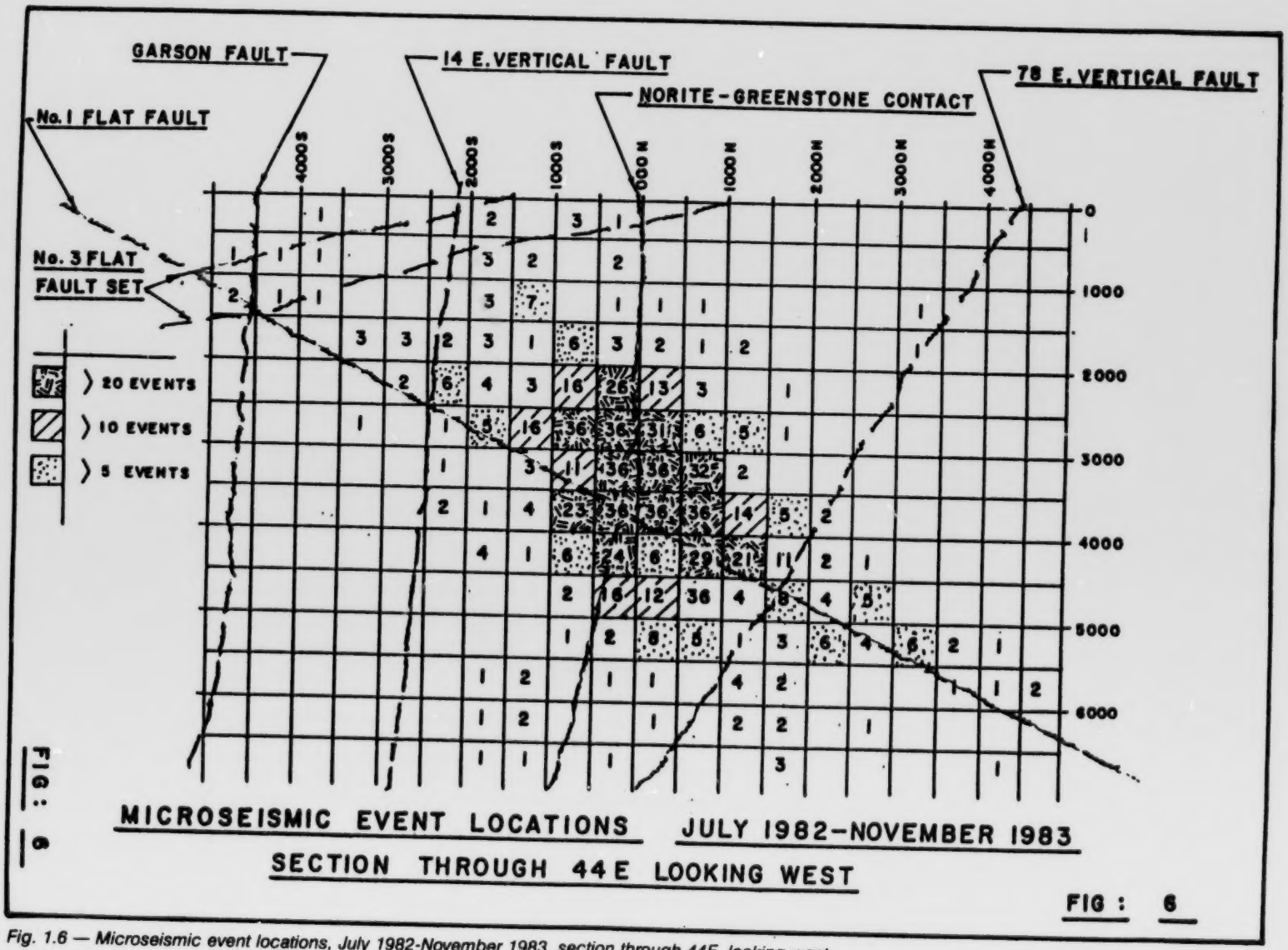

Fig. 1.6 — Microseismic event locations, July 1982-November 1983, section through 44E, looking west

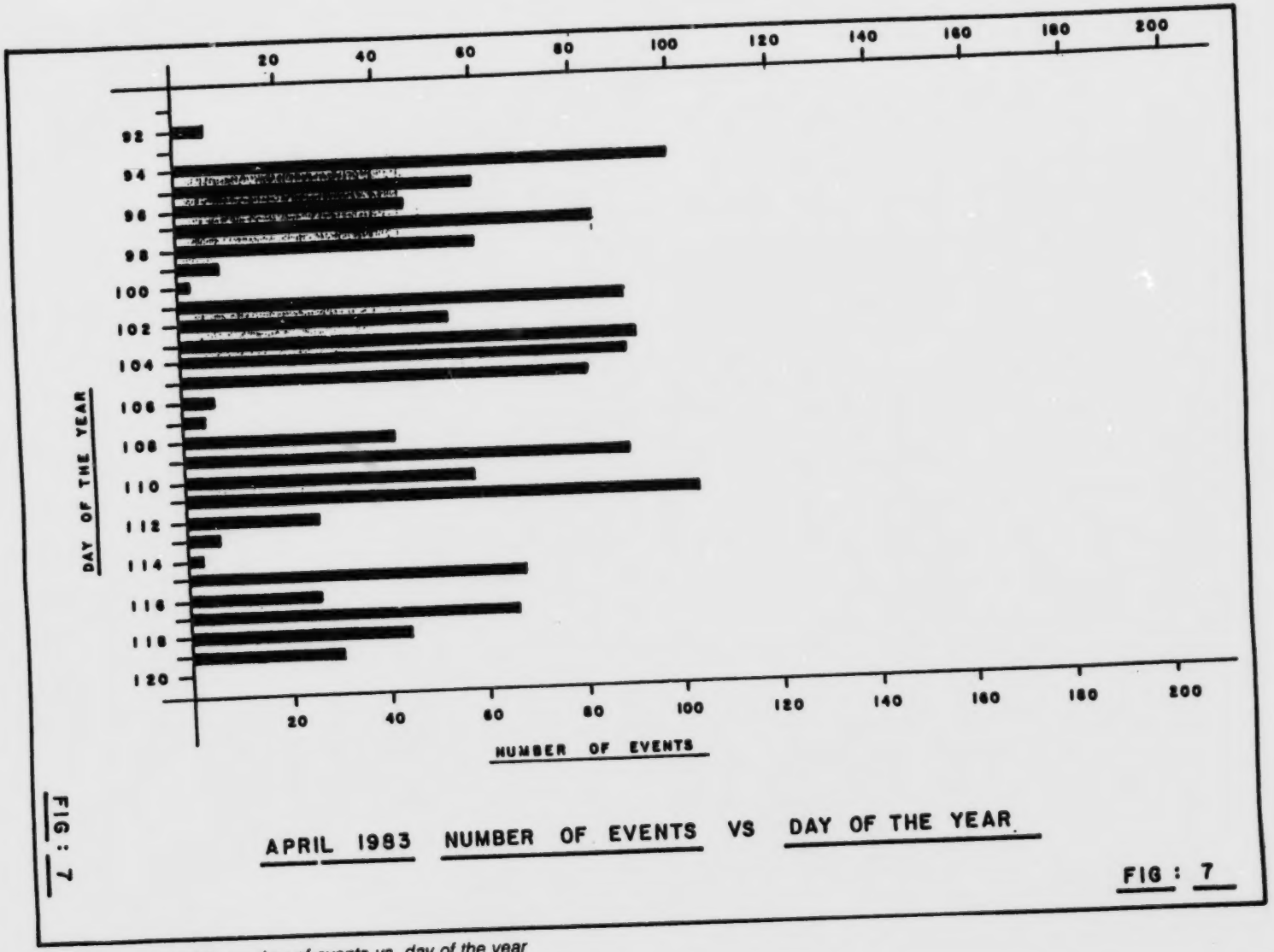

Fig. 1.7 — April 1983, number of events vs. day of the year

DISCUSSION

It should be noted that Dave West presented details of the events that occurred at No. 5 Shaft, Falconbridge Mine on June 20th, 1984. Four miners were killed as a result of these events. A printed version of the presentation was not available. However, the following discussion took place afterwards.

J. Cook: How much microseismic activity occurred prior to bursts occurring on June 20, 1984?

D. West: Before the events of June 20th, microseismic activity had not reached levels recorded during the six month shutdown in 1982. Typically the number of events per day were 15-20 during the shutdown, and there were fewer events than this prior to June 20th. We have an eight-channel system centred on the hoist room pillar monitoring microseismic activity in that pillar. The stope being mined and the sources of the first events were immediately to the east of the 3D geophone array. No microseismic precursors were recorded. A greater density of geophones on a mine-wide scale may have given precursory activity.

S. Bharti: No triggering mechanisms were obvious and the events were caused by the gradual effects of 50 years of mining, resulting in stress concentrations or increased shear stresses on the faults that were mobilized. Very little is known, internationally speaking, about mining-induced seismic events associated with faults.

D. West: Contrary to evidence on pillar bursts, we are not aware of published examples of microseismic anomalies prior to events of the fault-slip type.

P. Oliver: Please discuss the feasibility, or advisability, of leaving remnant shaft pillars.

S. Bharti: Falconbridge debated for many years about when and how the No. 9 Shaft hoist room pillar would be mined. It was decided to recover the pillar at the end of the life of the mine; thereby minimizing the risk to the remaining reserves. Obviously, if the mining sequences were being planned now, pillars would be avoided and mining would advance away from, rather than towards, any hoist room. However, decisions were made many years ago when circumstances were different and little was known about rock mechanics.

G. Hunt: What relationship has Falconbridge considered between mining-induced stresses and the fault-slip mechanism?

D. West: This was discussed by the Technical Committee and it was thought that perpendicular stresses across the faults would have been reduced by mining in the area. This may then have been a triggering effect.

S. Bharti: It's possible that high stresses in the hoist room pillar acted to maintain the "clamping' forces across the faults, such that movement occurred later than it would have done otherwise.

R. Cameron: Following the wet spring season, was there water on the faults?

D. West: While there is an increase in water ingress to the mine in spring, none of the faults appeared water-bearing. Therefore, lubrication of the faults by water was not considered a significant factor.

D. Morrison: Referring to an earlier question, the trigger levels on the monitoring system were set to a more sensitive level during the 1982 shutdown. These settings could not be maintained during normal working periods as the amount of data could not be handled. Therefore, the levels of microseismic activity during the shutdown cannot be directly compared with production periods.

* * *

MICROSEISMIC MONITORING AT INCO

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ABSTRACT

Inco has twice been involved in microseismic research. Once in the forties, with a rock noise count system, and now with a rock noise location system.

The history of microseismic monitoring is reviewed. The paper describes, from a not too technical viewpoint, microseismic source location theory as well as the selection, installation, and operational problems of the Creighton Mine system. Background drill bit noise levels are the limiting factor in system sensitivity.

SURVEILLANCE MICROSISMIQUE À L'INCO

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RÉSUMÉ

L'Inco a fait deux fois de la recherche microsismique, une première fois dans les années quarante pour mettre au point un système de comptage de bruits dans des masses rocheuses et une seconde, pour mettre au point un système de localisation des bruits dans des masses rocheuses.

Nous faisons un survol de l'évolution de la surveillance microsismique dans la présente communication qui décrit, d'un point de vue peu technique, la théorie de la localisation des sources microsismiques et qui expose les problèmes liés au choix, à l'installation et à l'exploitation du système installé à la mine Creighton. Le bruit de fond des outils de forage est le facteur qui limite la sensibilité du système.

MICROSEISMIC MONITORING AT INCO

INTRODUCTION

In 1938, L. Obert, of the US Bureau of Mines, while measuring sound velocities through pillars in a room and pillar mining operation, discovered that some pillars were generating sub-audible noises (microseismic), (1). A relationship was subsequently found between the amount of microseismic noise and pillar failure; noisy pillars ultimately failed while quiet pillars remained intact.

This discovery coincided with the start of a period of major research in Ontario under the auspices of the Ontario Mining Association (O.M.A.) into ways and means of predicting and preventing rockbursts. Microseismic activity became the most heavily researched topic. There were two projects, one at the Lake Shore Mine in Kirkland Lake and the second at Inco's Sudbury area operations. The work was carried out between 1940 and 1947.

At Inco, most of the research was done at Frood Mine. The main piece of equipment consisted of a piezoelectric sound pick up (geophone), an amplifier and a set of headphones. Listening stations were set up through the area to be monitored and the numbers of microseisms heard over a fixed period of three minutes or less were recorded for each station. Background noises from drills, ore and rock passes, crushers, trains, etc. generally limited counting to weekends, lunch, and shift-change times.

A high speed photographic oscillograph recorder was also used to make traces of both microseismic and background noise waveforms. It was hoped that analysis of the waveforms would reveal a specific frequency range where microseismic sound levels predominated over background noises.

Research in Ontario stopped in 1947 when it was concluded that the available technology could not be made to work. It was not possible to electronically separate out rock noises from background mine noises and this eliminated the possibility of continuous automated count systems. Manual counting was too labour intensive and was restricted to such a small percentage of the total time that the results precluded the ability to provide a warning system. The directions of noise emanations could not be determined and predictions were unreliable. High noise counts did not necessarily signify an impending rock burst and some rock bursts occurred after periods of low noise activity. At Frood Mine, it was concluded that most of the noises originated from failing pillars. Rock bursts could occur in any of the nearby quiet but intact pillars as a result of stress transfers from these failing pillars.

In the sixties, microseismic research was renewed in South Africa and then in the United States. Multichannel tape recorders were used to simultaneously record signals from a number of geophones installed in and around a monitored area, and source locations for the noises were determined from the arrival times.

In the seventies, research by the US Bureau of Mines in the Coeur d'Alène area led to the development of microprocessor-based microseismic source location systems. Automated source location systems have also been developed in South Africa; however, the problems inherent in accurately locating microseisms in deep, flat dipping reefs have required the development of complex minicomputer-based systems which analyse waveforms from a number of geophones for directions of travel and distances.

The first working microprocessor-based systems were installed in the Coeur d'Alène area of Northern Idaho. Early results mislead people into thinking these systems could generate reliable rock burst predictions. It was subsequently concluded that for the Coeur d'Alène area these systems would delineate burst prone areas and could be used to determine when a mining change should be made to improve rock burst control. They could also be used to determine when a mining change should be made to improve rock burst control, and to determine when and where destressing should be done, and to assess the effectiveness of a destressing program, but they could not be used as a warning system.

In the latter part of 1980, Inco purchased a 16-geophone microseismic source location system from Electro-Lab, Spokane, Washington to monitor mining between the 6600 and 7000 levels at Creighton Mine. The intent was to see if this new technology, which worked in the Coeur d'Alène area where the host rock is a massive quartzite and the veins are normally less than 3 m wide, would work for a large three dimensional orebody. Creighton Mine was chosen because it is the most seismically active mine we have. In 1981, the system was further expanded by the addition of 32 geophones to cover the entire mining area below the 5400 level.

This paper is oriented towards providing some insight into microseismic monitoring systems for those who might not be familiar with them. It deals with microseismic theory, the selection and installation of the equipment at Creighton Mine, and a hindsight review of the system. It does not deal with the question of the value of microseismic monitoring because we do not yet have the answers.

For those with a more technical bent who wish to know more about microseismic theory and systems, I recommend "Microseismic Applications for Mining...A Practical Guide", (2). It is available from NTIS, Springfield, VA, 22161, USA, (PB 83-180877).

MICROSEISMIC MONITORING OVERVIEW

When the stresses in rock approach about 80% of the failure load, many small intergranular microfractures begin to develop. Each microfracture is accompanied by a release of elastic (strain) energy in the form of a sound pulse. The energy of the pulse is proportional to the size of the fracture and the frequency is inversely proportional to the fracture size. Small fractures cause high frequency sounds which carry only a short distance (attenuate rapidly).

As the rock gets closer to failure, small microfracture zones begin to merge to form larger fractures. As the fracture size increases, the sound pulse energy increases; also, the sound frequency drops and carries a much greater distance. There is a drop in the number of fractures developed as the fracture size increases. Ultimately, the fracture size reaches the point where there is sufficient energy for a microseismic source location system to locate the noise source.

The hardware for a microseismic source location system consists of a group (array) of geophones with amplifiers connected to a central monitoring device by a network of cables which supply power to the geophones and transmit the geophone signals to the monitor. The monitor times the signal arrivals, solves for the event location, and transmits the coordinates, plus the day, time and energy level, either directly or through a computer, to a printer.

MICROSEISMIC SOUND WAVES

The velocity of sound in air is about 340 m/s. Sound travels faster in rock and the situation is made more complex because there are two forms of sound waves. **P** waves (compressional waves) have a velocity of about 6000 m/s in rock while the **S** waves (shear waves) have a velocity of about 3600 m/s.

The best way to describe the two waves is to consider the direction of motion of a point as each of the waves passes by. For P waves, the direction of motion is along the line of the travel of the wave, first forward and then back. The action is similar to that of cigarette smoke underground when concussion from a nearby blast causes the smoke to move backwards and forwards. Shear wave motion is at right angles to the direction of travel of the wave and is similar to the motion of an object floating on water as small waves pass by. However, in rock, the motion at right angles to the direction of travel of the wave can be up and down, sideways, or any other attitude in the plane at right angles to the direction of wave travel.

Sound radiates out from an event just as waves radiate outward in a circle from a rock tossed into still water. The difference, however, is that in rock the form is a sphere rather than a circle. It is commonly assumed that wave energy is constant around the expanding sphere, but this is true only for blasts which do not generate S waves. Microseismic events generate complex systems of both P and S waves. In some directions P waves predominate; in others S waves are predominant. Energy distribution is not constant around the surface of the sphere and the energy split between P and S waves is also directionally dependent.

It is commonly assumed there is only one path for the sound to travel between an event and a geophone. Sound in rock, as is the case for sound in air, reflects off surfaces and can be refracted by differences in rock properties. There are, therefore, many paths. The waveforms that reach a geophone from a microseismic event are the algebraic sum of all of the wave paths the sound travelled between the event and the geophone. The first arrival followed the fastest path. The latter part of the signal may have travelled up to 100 m further. Because of the different path lengths, there can be both destructive and constructive interference causing a reduction of frequency with distance; also there is the potential for elevated spikes in the waveform some time after the first arrival, (Fig. 2.1).

GEOPHONES

Most microseismic systems use velocity transducers for geophones because of their low cost and high output for the frequency range of 10 to 2500 Hz (cycles per second). Some systems use accelerometers to expand the sensitive frequency range above 2500 Hz, but accelerometers require more complex amplifiers and they lack sensitivity at the low frequency end.

Both types of geophone are directionally sensitive. The signal output of a velocity transducer is proportional to the component of velocity motion along the axis of the geophone. The same holds true for accelerometers, except that the output is proportional to the acceleration component causing motion along the axis of the accelerometer.

There are two types of velocity transducers; one measures vertical motion and the other horizontal motion. Vertical motion transducers must be mounted within five degrees of vertical to work properly; horizontal transducers within five degrees of horizontal. Accelerometers can be mounted at any attitude.

The directional nature of geophones along with the variability of the waveforms generated by microseismic events can lead to some unusual timing sequences. At Creighton Mine, where the velocity transducers are vertical sensing, there have been events where the nearest geophones on the event horizon have either not triggered their threshold detectors or have triggered on the S wave. Geophones above and below the event, but at greater distances, have triggered on the leading front of the P wave. The explanation is that the axis of the geophones above and below the event were oriented along the direction of travel of the P wave and sensed almost the full value of the wave motion. The axis of the geophones on the same horizon as the event were oriented at right angles to the direction of wave travel and could, therefore, not sense the P wave. They could sense the later-arriving S wave – provided the direction of transverse motion was not close to horizontal.

I selected vertical sensing geophones for two reasons. First, because our blast monitoring studies showed generally higher signal levels in the vertical direction and, secondly, because we could mount the geophones in the drift back. The geophones are installed in 54 mm diameter holes drilled 1.5 m deep to remove them from airborne noises and sound dampening from the shell of loose which surrounds openings at depth. The geophones screw into acrylic plugs which have been cemented into the hole ends with hydrostone (plaster of Paris).

There has been only one instance of an acrylic plug detaching and that was due to nearby blasting. Repeated attempts at recementing the plug failed until the old cement was drilled out.

Drill hole mounting of the geophones has been effective in blocking out the airborne sounds which so often cause triggering where the geophone is mounted on the back of the drift. Geophones are sensitive microphones. In the Coeur d'Alène area, with the geophones mounted on the drift back, one could hear conversations, water dripping, fans, etc. In our installations, the drill bit sounds, carried through the rock, mask out all but the most intense airborne noises.

When selecting geophone sites, one should avoid major noise sources, such as crushers, major ventilation fan installations, ore and rock passes, and L.H.D. haulage drifts.

For future installations, I would continue to mount geophones in holes drilled in the backs of openings. I would, however, seriously consider purchasing geophone systems with three orthogonal accelerometers and vector summing circuitry to output a signal proportional to the wave motion regardless of the direction of the wave motion. This would increase the system sensitivity and eliminate situations in which nearby geophones do not trigger thresholds while more distant ones do.

AMPLIFIERS

In any electronic network, particularly a microseismic network with long cable runs in openings containing phone, power, and, possibly, signal and trolley lines, there will be electrical noise induced into the geophone cables. The effects can be minimized by the use of shielded cables and by boosting the power of the signal at the signal source to a high value relative to any electronic noise. In Inco's installation, the geophone and amplifier are in a single case. There are connections which make it possible to select an amplifier gain of 40 db (100 times) or 60 db (1000 times). The geophone and amplifier are insulated from the case to eliminate the potential for ground current triggering.

We have connected our amplifiers to generate a 60 db gain and see no reason to try the lower setting. For future applications, however, I question the use of both a fixed gain amplifier and a fixed trigger level at the threshold. The reason for this questioning is the increased use of ITH (down-the-hole) drills which have an impact energy level sufficiently high to cause the system to try to locate every hammer blow. This can totally tie up the system and make it necessary to instruct the monitoring unit to ignore all geophones in the vicinity of the drill. The system becomes deaf at all times for the area around the drill.

The alternative is to use either an average constant output amplifier at the geophone with a fixed threshold trigger level, or a fixed gain amplifier in conjunction with an automatic threshold trigger unit. With the constant output amplifier, the amplification will be governed such that the level of the electrical signal caused by mine drills and other mechanical sources will at all times be just below the trigger level. On weekends and other low noise times, the system would be sensitive to low level seismic events. During noisy mining periods, amplification would be reduced and only those noises with energy levels above normal mining noise levels would cause triggering. With the alternative automatic threshold unit, the trigger level would be held just above the background noise level.

There is the possibility with either of these techniques for the system to lose sensitivity during periods of high seismic activity. The events could be so close together as to cause an upward shift in the event energy level needed to trigger the thresholds. Where the major noise source is a high energy drill, some lost information is acceptable because the alternative is no information. There is also the positive benefit of having the system automatically becoming sensitive to low energy events during shift-change and other quiet times.

CABLES

Belden 8723 cable is used throughout the Inco system. It was the cable recommended by the supplier at the time of purchase and has two individually shielded pairs of 22-gauge wire along with a ground bleeder wire. One pair carries the power to the geophone preamplifier and the second pair conducts the geophone signal to the monitoring unit.

Twenty-two km of cable connect the geophones at Creighton Mine to the monitoring unit on the 6400 level. The cables are installed away from power lines and phone lines and as remotely as possible from ore cars and other mobile equipment. Each cable is tagged with its geophone number at intervals not exceeding 20 m for identification while fault finding. All joints are waterproof and periodic loops of slack have been left in each cable to simplify cable repairs. Cable splices are in dry areas. There is only one ground point in the system and it is at the monitoring unit.

We discovered one fault that occurred when a cable was partially shorted. It would not blow the power supply fuse but it dragged the power supply voltage down to the point where the geophone preamplifiers ceased working. We installed terminal blocks with 0.1 amp fuses and quick disconnects on each geophone cable.

We constantly average two geophones out of action because of cable damage, with most of the damage being caused by roofbolts in ore cars. Trouble-shooting equipment consists of a small portable oscilloscope, a digital multimeter and a simple phone company audio signal generator with a receiver probe. We also enlisted the aid of our telephone people to teach us some of the tricks of the trade in locating cable faults. Intermittent faults and bruised cables are the most difficult to locate.

MAIN MONITORING UNIT

The main monitoring unit consists of series of thresholds, one for each geophone, an event timer, a dedicated microcomputer, an input/output port, a calendar day clock, an energy integrator, a power supply, and a phone jack and channel switch to allow one to listen to each geophone.

THRESHOLDS

The trigger levels of the thresholds can be adjusted with a small screwdriver up to a maximum of four volts peak-to-peak. There is also an LED (light emitting diode) on each threshold unit which flashes when the threshold is triggered. These can be used to spot noisy channels and to set the trigger level.

The most sensitive way of adjusting trigger levels is to adjust each threshold during mine-opening periods to just above the point where the LED stops flashing. The problem with this approach, however, is that the system can pick up a large number of events and noises with poor to unusable locations. The person screening the data can be overloaded by the total amount of paper generated.

In our case, we set trigger levels at two volts peak-to-peak using a signal generator to input a two volt peak-to-peak sine wave to each channel. We checked to see if there were geophones triggering on local noise and had to raise the trigger levels on geophones near an orepass to between 3 and 3.5 volts peak-to-peak. The actual setting can be determined by inputting a sine wave to both the threshold and an oscilloscope, and by increasing the signal strength until the LED begins to flash.

The total quantity of output can be controlled by raising or lowering trigger levels.

EVENT TIMER

The timer in the event timing device starts when a channel is triggered and runs for a preset window time. While the window is open, the event timer records the trigger times of other channels relative to the window start time to an accuracy of 100 usec (0.0001 sec). At the end of the window period, it sends to the processor the trigger channel number and the number and times of any other channels triggered during the window period. It then resets to wait for the next triggered channel to open the window for a new event.

The duration of the timing window can be set at any value between zero and 0.999 sec. The setting time should not exceed the time it would take a P wave to travel the longest distance across the geophone array. Too long a window period will capture geophones triggering on several noise sources and there will be an excess of unreliable locations. A normal setting time for a window is 100 msec (0.1 sec).

ENERGY INTEGRATOR

One geophone, normally placed some distance back from the orebody, is connected to both a threshold trigger device and an energy integrator. During an event window, the energy integrator approximates the amount of energy in the signal from this one geophone. It is not necessary for this geophone to trigger its threshold to have the energy integrated.

The output of the integrator is adjustable. We left ours at the original setting. The measured levels have relative, rather than absolute, values and we relate energy levels for each area to energy levels from blasts where the quantity of explosive is known.

There is an apparent straight line relationship between energy and the integrator's output up to a point. Above this point, a considerable increase in event size is needed to increase the energy integrator reading by a small amount.

At the end of the window time, the energy value measured by the integrator is sent to the processor.

PROCESSOR

The processor is a microcomputer with memory and a dedicated program written in machine language. The program is permanently fixed (burned) on a PROM (Programmable Read Only Memory chip). Program changes require replacement of the PROM. Part of the main memory has a battery backup and it is in this memory that the geophone coordinates and a P wave velocity are stored. The processor also has an I/O (Input/Output) port to communicate with either a terminal or a computer.

In the event of a short-term power failure, the system will restart on its own and be fully functional. Should the power failure stretch out, only the geophone coordinates and input P wave velocity values are lost. The system will restart and record the event time, the channels and times, and the energy level. It will be unable to calculate locations until the geophone coordinates and a P wave velocity have been read back into memory.

When the event time signals the start of an event window, the processor reads the calendar day clock and stores in memory the day and time to a resolution of 0.01 sec.

When the event window closes, the processor stores the event channel numbers and times recorded by the event timer and the energy level. With the newer PROM programs, it also increments by one the trigger count registers on each of the triggered channels.

The processor checks to see if there are five or more triggered channels, including the window triggering channel. If fewer than five channels triggered, the event is discarded because there is insufficient data to solve for the location. If five or more channels were triggered, the processor begins solving for the event location.

When possible, the program in the processor uses the arrival times at six geophones, including the triggering geophone, and the geophone coordinates to form four equations to solve for the four unknowns of event northing, easting, elevation, and the average P wave velocity. If only five geophones triggered, the P wave velocity in memory is used to reduce the solution to three equations with three unknowns. Mathematical details for the solutions are given in the USBM publication referred to previously (1).

The accuracy of a solution is dependent on the accuracy of the arrival times and geophone coordinates. We have control on the accuracy of the coordinates, but chance plays a role in the arrival times. The system cannot discriminate between channels triggering on an event and channels triggering on some unrelated noise. During any window time, there is a probability that one or more of the triggering channels may not be related to the event. In addition, the distribution of the P and S waves, coupled with geophone orientation sensitivity problems, can cause later triggering on some of the channels including the triggering channel.

Solution accuracy is most sensitive to timing errors on the trigger and second channels. To compensate, the system does up to four solutions depending on the number of triggered geophones. With eight channels triggered, the system will give three solutions for both location and velocity and a fourth solution for location using the input velocity. It uses the first six triggered channels for the first solution; channels two to seven for the second solution; channels three to eight for the third solution; and channels four to eight and the input velocity for the fourth solution. Seven triggered channels give three solutions; six give two solutions; and five just the one solution. Occasionally, the system will report N.S. (no solution) and this occurs when mathematical problems develop such as when the triggered geophones are in one plane and there are two valid location solutions.

When two or more of the solutions are within 15 m, there is a good probability the location is reasonable. There is even more assurance of a reliable location if the calculated velocities are within plus or minus 1000 m/s of the normal P wave velocity. However, there can be good solutions with unrealistic velocities.

The processor stores the information for output to a printer in a, "first in first out", memory buffer for transmission through the output port to either a terminal or a computer. Whenever the processor is not busy with a new event, it is available to transmit the contents of the buffer. It ceases transmission whenever an event window is triggered or when the buffer is empty.

OUTPUT

The input/output port on the processor conforms to the RS-232 computer standard commonly used to connect terminals to computers. It permits the exchange of data at preset speeds ranging from 300 to 9600 baud (30 to 950 characters per second). The data format used by the system is ASCII and any standard ASCII terminal or printer with keyboard can be connected to the processor. A computer can also be connected.

The minimum system requires the use of a printer with keyboard to record the output data on paper for subsequent manual analysis. It is also needed to input the geophone coordinates, a P wave velocity, to enable and disable channels, to check that the values input into the processor have not been changed and to verify the status of each channel. On the newer systems it is also used to check for noisy or dead channels by printing out the counts in the trigger count registers.

The printer should be a robust device with a minimum of 80 columns of characters across the page width. It operates 24 hours a day and the amount of printing is a function of mine activity and of the sensitivity setting of the thresholds. In our case, the average printer output ranges between 25 and 50 pages per day.

A printer speed capability in excess of 100 characters per second is recommended. The memory buffer can store up to 50 events but the processor is capable of capturing and storing events at a much faster rate than data can be printed. In addition, each time an event occurs, data transmission stops. The faster data can be printed, the less chance there will be for lost data due to buffer overflow.

The preferred output is to a computer which can accept data at a much faster rate than a printer. The computer can be used to sort out the incoming data, to carry out more rigorous location solutions where the effects of bad timings on location accuracy can be minimized, and to store data for subsequent analysis by the operator. Certain basic data would still be sent to a printer by the computer but the total printer output would be much less than for systems without a computer. The computer can also be used to check for and to disable noisy channels and to enable shut down channels after the noise has stopped.

The computer should have a minimum of ten megabytes of hard disc storage for subsequent on line analysis of event patterns and two dimensional graphics capabilities to plot events relative to mining. A real time operating system is essential to ensure the computer is available at all times to receive event data while allowing the operator to run other programs. Unix is not a real time system.

The system sensitivity can be increased where a computer is used to sort out poor data. In addition, more data would be kept for analysis because reliable solutions can be calculated for events which would otherwise have to be rejected because the event processor solutions are unrealistic.

PROCESSOR LOCATION

There are three possible system configurations; one with both the processor and output device underground; the second with the processor underground and the output device on surface; and the third with both the processor and output devices on surface. With the processor underground, cable lengths are minimized and having the output device underground simplifies operation of the system. The operator can listen to channels to assess noise. He can disconnect, disable or adjust the thresholds on noisy channels and can immediately tell if a channel has gone dead.

The disadvantages of having the output device underground relate to dust, temperature, humidity and mine access. The monitoring station requires filtered air, air conditioning, and an outer room for the operator to change clothing before entering the equipment area. Room is required for a drafting-size work desk to spread prints and a file area to store prints and other documents. The locations of weekend noises are not available until the operator goes underground and begins sorting out the weekend printout.

Only the processor is underground at Inco. The processing unit is inside a commercially-available, oil-and-dust-tight steel cabinet with front and rear doors. A small circulating air fan blows on the power supply to prevent the development of hot spots and to make the enclosing cabinet a heat radiator. The cabinet is located near the source of fresh air on the level to minimize the potential for condensation.

The connection between the processor and the output device required the purchase of two modems with a maximum data transmission rate of 9600 baud (950 characters per second). Data transmission ties up two phone lines and these are matching pairs. The phone lines bypass the exchange switchgear because this is a source of electrical noise. It was necessary to check at every junction box from the processor to the output device to see that unused phone lines were disconnected from the terminals used by the dedicated phone lines and that the wires were matching pairs. Data transmission couldn't be accomplished until this was done.

We originally set the data transmission rate at 1200 baud which is below the 180 character per second speed of our printer. We are now transmitting at 9600 baud in preparation for connection to a computer.

Where cable runs are short, the processor can be installed on surface.

Regardless of where the processor is mounted, the electrical environment must be considered. The minimum requirement is a constant voltage transformer to avoid brownout problems and to promote system longevity.

The maximum requirement is a constant voltage uninterruptable power supply with both noise and spike protection. We have been fortunate and have thus far required only a constant voltage transformer.

SYSTEM OVERVIEW

The system has required almost no maintenance apart from the problems associated with roofbolts in ore cars damaging the geophone lines, and new development headings requiring the temporary removal of lines. There have been two episodes of phone line noise; one related to a terminal connection that loosened and was easy to locate. The other proved to be more difficult to locate in that it was an intermittent fault. One geophone broke down and was returned to the supplier for repair.

The first program in the processing unit had a bug in it which caused the system to hang when there was phone noise or when an incorrect sequence of characters was punched in by the operator. A revised PROM program eliminated the problem. The more recent intermittent phone noise which affected only the phone pair for data transmission from the terminal to the processor caused a different level of control loss to the system each time the problem recurred. However, the system continued to function, provided we did not try to change anything.

The original PROMs were in short supply, expensive, and had a high failure rate during the programming process. The system supplier revised the processor board in later systems to take a different type of PROM. Program modifications of older systems now require that the processor board be returned once for modification to accept the new type of PROM. We plan to upgrade our system to include channel trigger count registers and this will require shipping the processor board back to the supplier. The estimated system downtime is three weeks.

Source location accuracy is dependent on accurate timing of the first arrival of the P wave. Our experience has been that the accuracy of a location is related to the magnitude of the event relative to the setting of the trigger levels of the thresholds. The higher the energy level, the more accurate the location. With rock bursts, we have seen all four solutions focusing within a 3 m diameter sphere. For low energy events, the radius of the sphere can expand to 100 m.

For the 1982-83 eight-month shutdown, we lowered the settings of the thresholds to 0.5 volts peak-to-peak. There was an immediate drop in the energy level of an event required for an accurate location. With the resumption of operations, the threshold settings were returned to normal levels, as were the energy levels required for reliable locations.

Figure 2.1 shows why this occurs. It is the plot of a low level microseismic waveform and there are at least four different timing points where a threshold would trigger, depending on the threshold setting. For a high energy event, all nearby geophones trigger on the first P wave arrival, regardless of the geophone location and orientation. As the event levels lower, timing errors increase.

The second timing problem occurs because of channels triggering during an event window, which are not related to the event. There are instances where two or more events occur in the same timing window.

The third timing error is related to seismic velocity zoning. Seismic velocity varies with stress and with the specific gravity of the medium. Massive sulphides, with specific gravities in excess of 4.0, can reduce seismic velocities by as much as 20%. We normally locate stope blasts, where the average charge weight is between 3 and 4 kg, to within 6 m of the blast. Where the seismic waves travel through massive sulphides, the accuracy slips to about 25 m.

We have found a zone of elevated seismic velocity in the rock immediately surrounding mining, which correlates to the expected high stress zone around mining excavations.

We have experimented with the effects of an incorrectly-input seismic velocity on solution accuracies. We find that a seismic velocity slightly below the true velocity has less effect on the solution accuracy than is the case where the input velocity is slightly greater than true.

ITH drills are causing a serious noise problem. Up to 22% of our geophones required disabling with just two drills operating.

Without research, a microseismic system will require one full time operator. Occasionally help will be needed to repair cables. Research work requires a second person.

CONCLUSIONS

The microseismic system is capable of locating ground failure noises with an energy level equal to or greater than that generated by 2 kg of explosives.

It has not yet been determined if the capacity of the system to locate energy levels below that generated by 2 kg of explosives is needed to provide timely problem warnings.

There are timing accuracy problems inherent in the system for the low energy events. An online computer is needed to improve solution accuracies using least squares methods to minimize the effects of timing errors.

The use of an online computer to screen out blasts and unreliable locations should permit lowered threshold settings to reduce the energy levels needed for reliable locations. There should be increased data available for forecast purposes.

Research should be carried out to determine the sensitivity gains possible using orthogonal geophone clusters in place of today's unidirectional pickups.

Automatic thresholds are now available and should be used. Data may be lost during high levels of seismic activity but this should be more than offset by the information gained with lowered thresholds during quiet periods.

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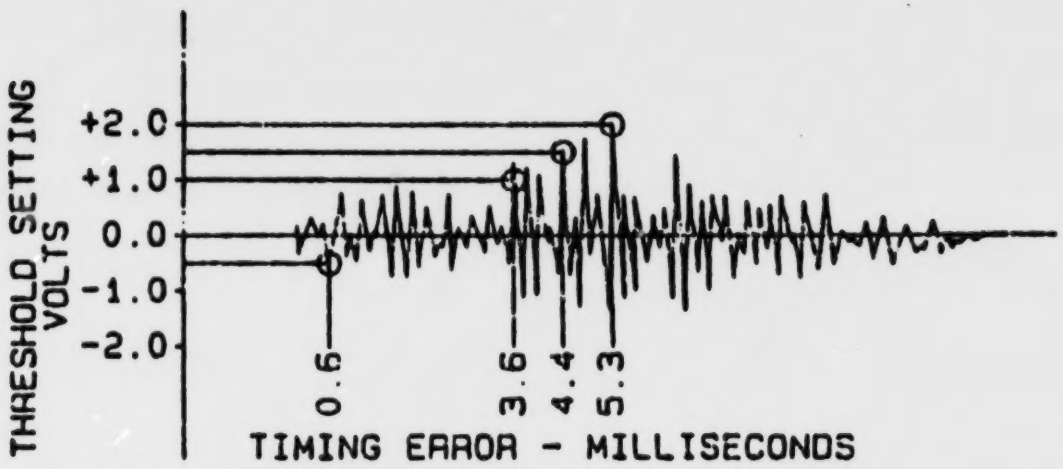

FIG. 1 - MICROSEISMIC WAVEFORM EFFECT OF TRIGGER THRESHOLD SETTINGS ON TIMING ERRORS

Fig. 2.1 — Microseismic waveform effect of trigger threshold settings on timing errors

DISCUSSION

Phil Oliver described a series of seismic events that occurred at Creighton Mine on July 6th, 1984, while the mine was on shutdown. One of the events was measured at magnitude 4.0 and was felt in the centre of Sudbury, 20 km away. While a copy of the presentation was not available for publication, the discussions are included here.

T. Yu: Have you tried plotting events over different time periods?

P. Oliver: Only in one case (for events during July 6/84). We consider that our system is not sensitive enough to detect precursory events, only the failure itself. With only one technician available for the microseismic monitoring project, the research aspects have recently been reduced. It is hoped that the use of a new minicomputer will help in mapping the development of the failure envelope around the openings.

One question still has to be answered. Increased microseismic activity is well known to occur prior to failure of small cores in testing machines, at perhaps 80% of ultimate strength; however, will precursory events be produced prior to failure in large samples or in the rock mass?

* * *

CASE STUDY OF MICROSEISMIC MONITORING OF THE "F-2" ZONE AT CAMPBELL RED LAKE MINES LIMITED

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ABSTRACT

All of the rock bursting at Campbell has been in remnant pillars associated with shrinkage and overhand cut and fill mining. In order to better understand these rock burst areas and to pinpoint rockbursts, a microseismic system was ordered in January, 1983, and was fully operational by July, 1983. Two main areas of concern at that time were the "F" and "F-2" zones. The "F" zone is a shrinkage area, almost completely mined out, of the western extremity of the mine. Deteriorating ground conditions and several rockbursts forced production to stop in September, 1982. Because of single access into the zone and poor ground conditions, a good array of geophones was not in place when violent bursting occurred in late December, 1983. From December 30, 1983, to January 4, 1984, 120 events over energy 500 (MP 250 energy) and three large bursts, Richter 2.7, 2.8 and 3.0 occurred. The 'F-2' zone is a smaller shrinkage zone east of the 'F' zone which was accessible and nad parallel drifts where geophones could be strategically placed.

This paper will focus on the microseismic data gathered from the "F-2" zone for nearly one year before a burst occurred.

ÉTUDE DE CAS DE SURVEILLANCE MICROSISMIQUE: ZONE "F-2" DE LA CAMPBELL RED LAKE MINES LIMITED

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Campbell Red Lake Mines Limited

RÉSUMÉ

Tous les coups de charge à Campbell se sont produits dans des piliers abandonnés, associés à l'exploitation par chambres-magasins et par remblayage en gradins renversés. Afin de mieux comprendre les zones de coups de charge et de localiser ces derniers, un système microsismique a été commandé en janvier 1983 et, dès juillet 1983, il était opérationnel. Les deux zones principales qui nous préoccupaient à cette époque étaient les zones "F" et "F-2". La zone F, zone d'exploitation par chambres-magasins, presque complètement épuisée, est située à l'extrémité ouest de la mine. La détérioration du sol et plusieurs coups de charge ont conduit à la cessation de la production en septembre 1982. L'accès unique vers la zone et les mauvaises conditions du sol n'ont pas permis de mettre en place un bon réseau de géophones à temps pour enregistrer les violents coups de charges de la fin de décembre 1983. Du 30 décembre 1983 au 4 janvier 1984, 120 événements d'une énergie supérieure à 500 (énergie MP de 250 MP) et trois grands coups de charge, de 2,7, 2,8 et 3 à l'échelle Richter, se sont produits. La zone F-2, qui est une plus petite zone d'exploitation par chambres-magasins, située à l'est de la zone F, était plus facilement accessible; elle présentait aussi des galeries parallèles où l'on a pu placer stratégiquement des géophones.

La présente communication traite plus particulièrement des données microsismiques obtenues à partir de la zone "F-2" pendant presque une année avant qu'un coup de charge n'ait eu lieu.

CASE STUDY OF MICROSEISMIC MONITORING OF THE "F-2" ZONE AT CAMPBELL RED LAKE MINES LIMITED

INTRODUCTION

Campbell Red Lake Mines is situated in Balmertown, Red Lake District of northwestern Ontario (Fig. 3.1). It is a primary gold mine with a daily production rate of 1070 STPD from a single 4075 ft (1200 m) shaft. Production started in 1948 with a 600 ft (190 m) shaft and using the shrinkage stoping method of mining. Today production is from the 1000 ft (300 m) to the 300 ft (900 m) horizons and is 20% shrinkage, 70% overhand cut and fill, and 10% development.

GENERAL

There are two main vein structures at Campbell. Replacement veins range from 2 ft (.61 m) to 30 ft (9.14 m) wide (G and L zones); quartz carbonate fracture filled veins range from 5 ft (.15 m) to 3 ft (.9 m) (A, F, F-2, and NL zones). Andesite is the host rock for all veins (see Fig. 3.2). At the beginning, both narrow and wide veins were mined using shrinkage stoping. As mining progressed deeper, the wider replacement type zones were converted to cut and fill and by 1980 most mining below the 2200 ft (670 m) horizon on all zones had been converted. Cavo 310's and slushers are used to move muck in the stopes and battery locomotives are used to tram on all levels.

F-2 ZONE

The F-2 zone was found to the north of the access drift to F zone by diamond drilling on the thirteenth level. Ore was outlined by drifting on 13 and 14 levels, then a conventional raise was driven between levels. Boxholes were placed at 27 ft (8.2 m) centres along the entire strike of the ore, then timbered gate chutes were constructed. In the same manner, the ore was mined from the fifteenth level until it pinched out above the eleventh level (see Fig. 3.3). The normal sill pillar left in place was 18 ft (5.5 m). The only ground problems encountered were in 1525 W. drift where *heavy* ground conditions occurred as the drift advanced through the chloritic altered rock contact and a lamprophyre dyke. Timber sets and mechanical bolts were put in and mining continued.

When the 1525 W. **A** and **B** stopes were complete to sill height (80% extraction), the drift timber and chutes had deteriorated badly and the remaining broken muck could not be pulled out. In order to retrieve the broken ore in the stope and still have access to F zone, a bypass drift was driven around the original 1525 W. drift (see Fig. 3.4). Draw points were put into the footwall of the stope above the original chutes and some of the remaining muck pulled.

To recover the remaining ore in place in the F-2 zone above level 15 the drifts on levels 14, 13 and 12 were renovated for longhole drilling. Drilling began in January, 1982; a drop raise was blasted in February on level 14; and drilling continued until June, when another cut was opened. On October 1st, two boxholes and 40 ft (12 m) of sill were blasted on level 14, (500 t).

Another blast of similar size was taken on October 15th, and immediately after, the boxhole adjacent to the opening burst (see Fig. 3.3). All activity was stopped except for pulling broken muck from 1525 W. stopes. On November 2, No. 20 pillar in 1525 W. drift burst, but did not damage the bypass drift. After these events, it was decided that drilling could not resume until the area was monitored with a microseismic system, and that all of the ore would be blasted at once after the drilling was complete.

MICROSEISMIC MONITORING IN THE F-2 ZONE

GEOLOGICAL CHARACTERISTICS

The F-2 ore zone consists of gold bearing quartz-carbonate veins, formed as fracture fillings along penetrative cleavage within the host andesite and altered rock units.

The ore vein has a 130/65 SW attitude and varies in thickness from 6" to 3', exhibiting boudinage or pinch and swell texture. The highly elastic/brittle andesite rock unit is a buff grey, medium grained, silicic rock. The altered rock unit is considered to be an altered ultramafic/mafic intrusive rock, with mineralization predominantly chloritic but with varying to talc rich parts.

The highly elastic/brittle nature exhibited by the andesite unit is the main factor contributing to the violent pillar failures recognized at Campbell (see Fig. 3.5a, 3.5b, 3.5c).

MICROSEISMIC MONITORING SYSTEM

The microseismic monitoring system at Campbell consists of a 32-channel Electro-Lab MP-250 processor, with all geophones being velocity gage transducer type. The geophone array was designed to provide for local monitoring of specific areas and mine wide monitoring, to delineate potential problem areas within the underground mine.

A PDP 11/23 plus minicomputer is used for data acquisition and event processing from the MP-250. Event source locations are determined by the least squares method and by a technique which compares general block solutions for best fit. All microseismic activity is analyzed by event frequency in relation to mining activity and is plotted in both longitudinal section and plan.

A single channel portable accelerometer type geophone is also used. By listening-in between shifts in the mine, a relative background level of event counts/minute can be obtained for a problem area.

GEOPHONE NETWORK — F-2 ZONE

A *tight* geophone array was installed within the F-2 mining zone to monitor pillar stability while the longhole drilling was taking place. A combination of past burst history and high extraction ratios in this mining zone indicated the need for extra microseismic monitoring (see Fig. 3.3).

At present, eleven geophones are installed between 12 and 15 levels in this zone, with a maximum 200 ft (60 m) spacing (see Fig. 3.6). For this geophone array, a source location accuracy of less than 10 ft (3 m) was determined from known blasts.

Starting in January 1983, microseismic activity was monitored using the Electro-Lab single channel unit. A background noise ratio at the lowest threshold setting was established at a stable 6-8 counts/minute. The MP-250 began recording activity in August, 1983.

Figures 3.7a and 3.7b show a number of events and average energy of event per day from F-2 zone, July 1983 – July 1984, as recorded by the MP-250 system.

Event frequency with respect to mining activity shows:

1. There is a direct correlation between increase in microseismic activity and blasting of the slot raises in 1325 and 1425 sill pillars.
2. Longhole drilling did not trigger any microseismic activity.
3. The drawing of broken muck from 1525 stope caused an increase in microseismic activity in the area.

Following the rockburst in No. 6 boxhole pillar on March 30, 1984, drawing of broken muck from 1525 stope was discontinued in order to determine if there was a relationship between drawing broken muck from the stope and pillar stability.

A sudden decrease in microseismic activity was immediately recognized, and this suggests that the broken muck was providing significant support to the stope walls, and that partial drawdown resulted in stress transfer to the pillars in the mining zone.

From Fig. 3.8 it can be seen that the microseismic activity was concentrated in the 1425 sill and boxhole pillars between the slot raises, and in the west abutment of 1325 near the slot raise.

From September 1983 to March 1984, there was a considerable buildup in microseismic activity near the second slot raise in 1425, leading to the rockburst in No. 6 boxhole pillar, with the effects being felt on surface.

A number of factors could be recognized which contributed to the rockburst in this pillar.

1. 80% ore extraction in the mining zone resulted in high stress concentrations in the sill and boxhole pillars.
2. Proximity to the andesite/altered rock contact (see Fig. 3.5).
3. Spatial relationship of this pillar to the second slot raise in 1425 W. sill.

RECOGNIZED PILLAR REACTIONS

The correlation between microseismic activity and extraction of the drop raises in the sill pillars indicated that ore extraction in the area was maximum for traditional shrinkage mining. Boxhole pillars were showing signs of high stress levels prior to the rockburst. Spalling and tangential cracking was occurring along the upper hanging wall and lower footwall sides of the pillars at drift level, and tension cracks could be recognized along exposed pillar sides. Also, resin rebar rockbolts installed into the hanging wall along No. 6 boxhole pillar had their bearing plates sheared off approximately two weeks prior to the rockburst in the same pillar (see Fig. 3.9). Increased wall closure and microseismic activity was a direct indication of increasing rock stress.

Visual inspection of the boxhole pillar following the burst, and source location from microseismic data, indicated that the pillar had burst from upper footwall to lower hanging wall sides.

Prior to the rockburst in No. 6 pillar and while muck was being drawn from the 1525 W. stope, there was a noticeable change observed on the 1425 W. drift. However, after the burst had occurred, and mucking was discontinued, there was a decrease in activity and no recognizable deterioration occurred in the drifts.

Frequent large muck removed through the drawpoints and also observed through the drop raises on 1425 has indicated that some recorded activity may have been a result of sloughing from the stope walls.

CONCLUSIONS

Prior to the installation of the MP-250 system, hazardous site inspections had to be conducted in order to locate rockbursts felt on surface. The ability to inform the underground department of rockburst locations has considerably improved safety and confidence of mine personnel.

As an engineering tool, the MP-250 system has proved useful in delineating potential problem areas. When used in conjunction with local mining geometry and ground conditions, a relative measure of pillar stability can be obtained.

The most important thing to keep in mind is that a microseismic system only gives you raw data for locations and energy of events. A keen interest and diligent study of the data along with observations underground are necessary for proper interpretation and confidence-building in the system. Good daily records and back analysis have to be an ongoing process if we ever hope to reach the point, if this in fact is possible, of anticipating rockbursts at a mine.

In order to expand our capabilities, 16 accelerometer channels have been added to the system. A further addition of 16 channels can be adapted to the processor at a later date, if necessary.

ACKNOWLEDGEMENTS

The author would like to thank Dr. Wilson Blake for his help, guidance, and his constant encouragement; Campbell Red Lake Mines for the opportunity to present this paper; and also Dave Brown for his help in presenting the graphics.

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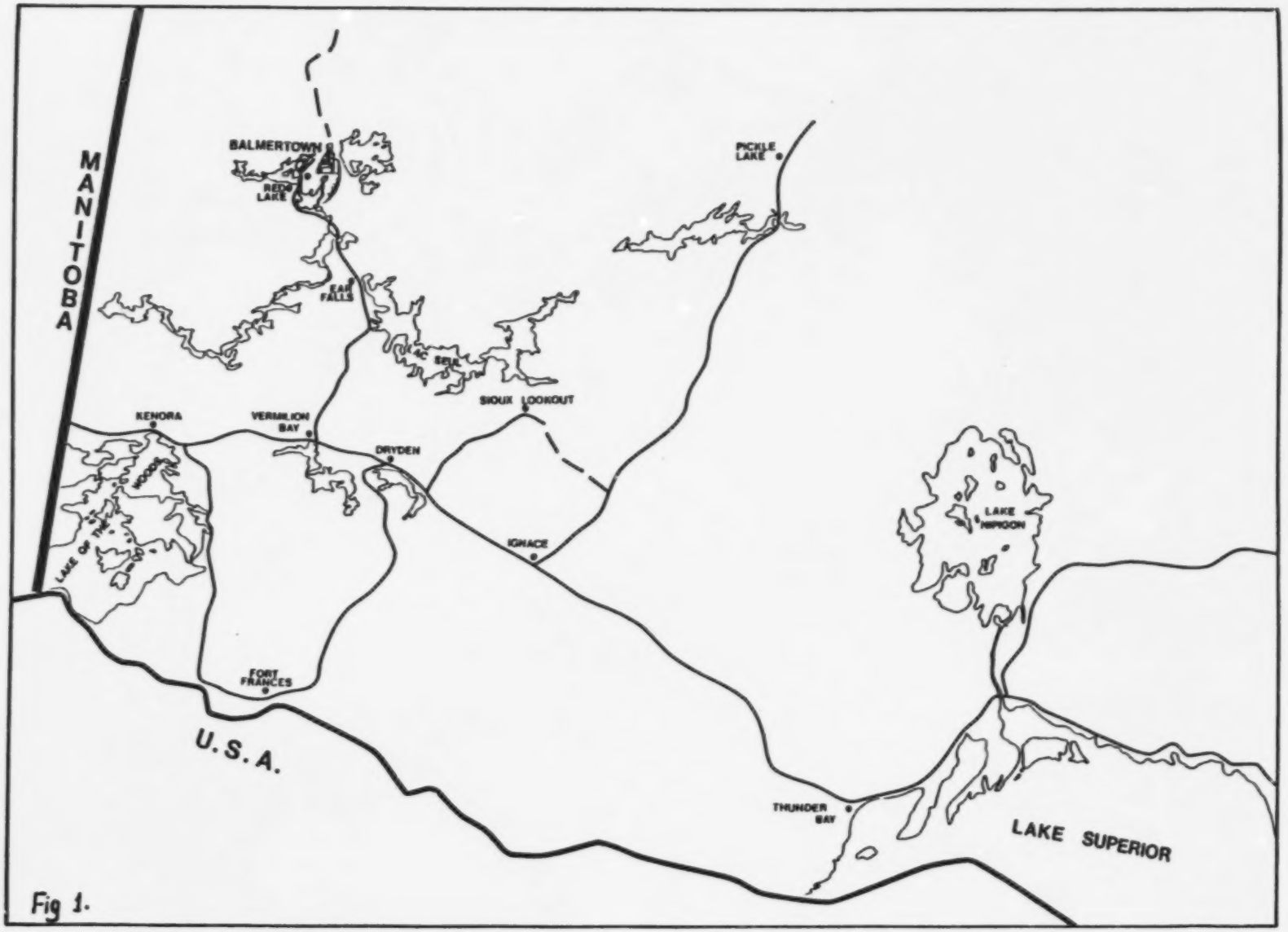

Fig. 3.1 — Location of Campbell Red Lake Mine

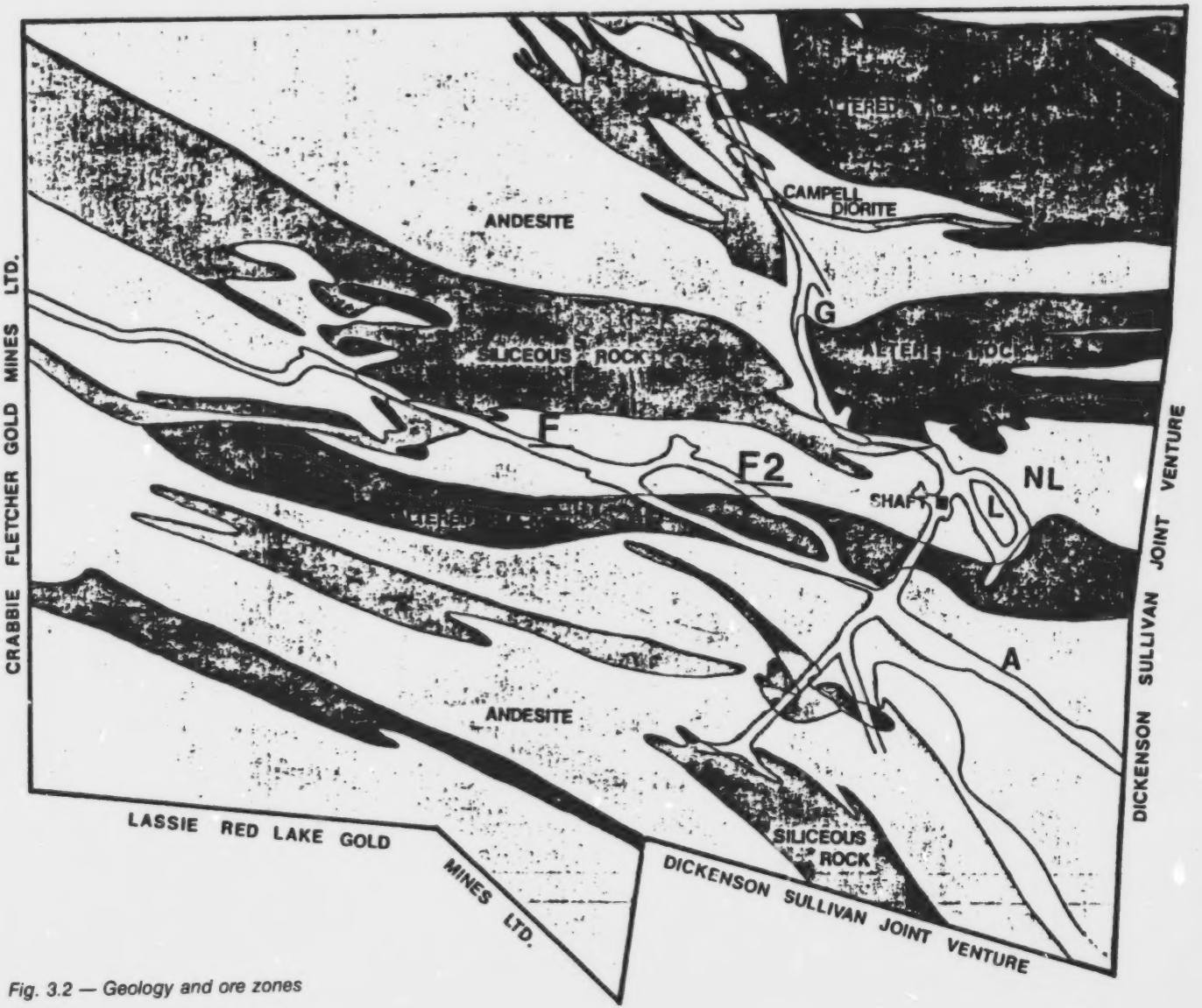

Fig. 3.2 — Geology and ore zones

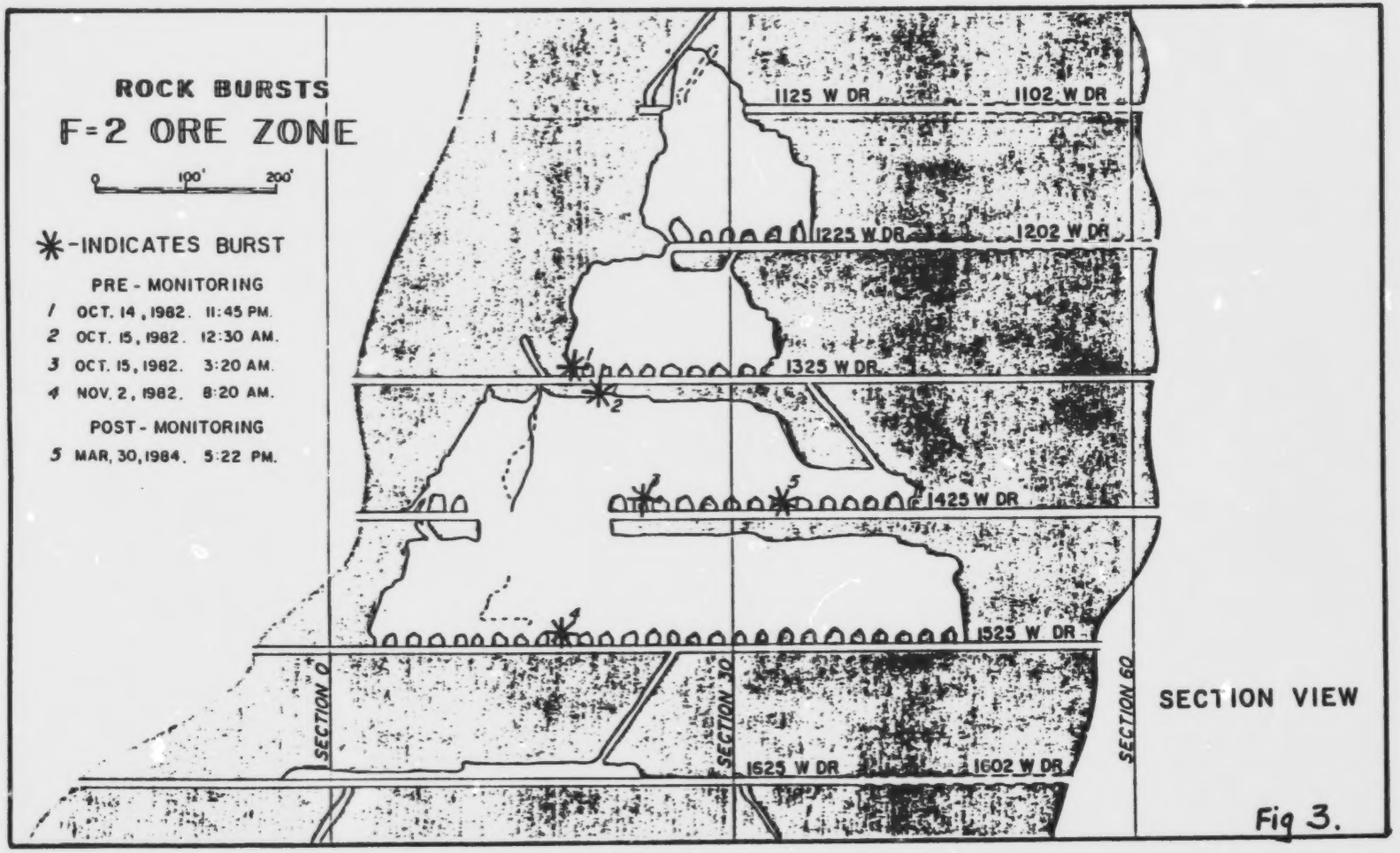

Fig. 3.3 — Longitudinal section of F-2 zone showing burst locations

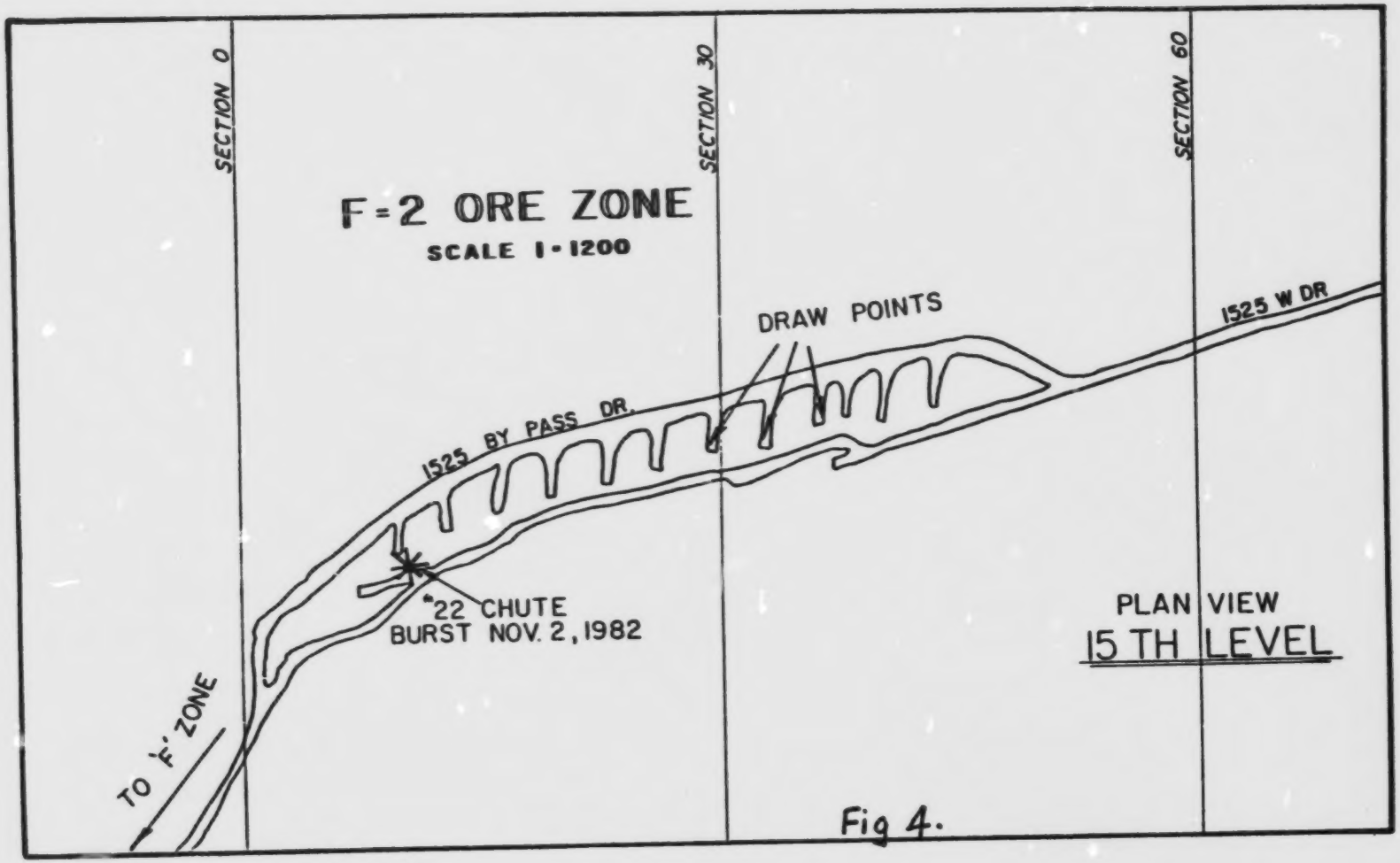

Fig. 3.4 — Drawpoint system: 1525 W. BP drift

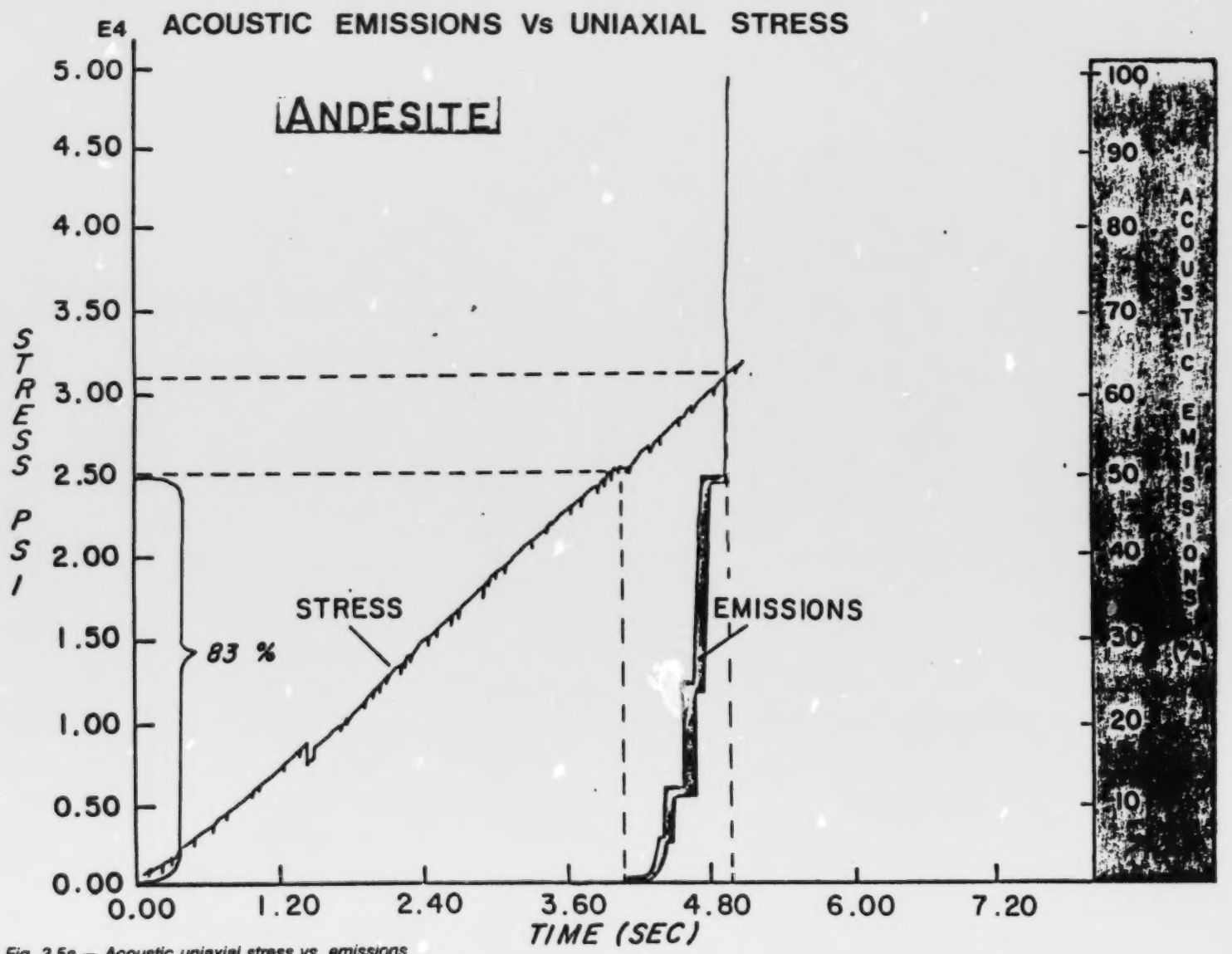

Fig. 3.5a — Acoustic uniaxial stress vs. emissions

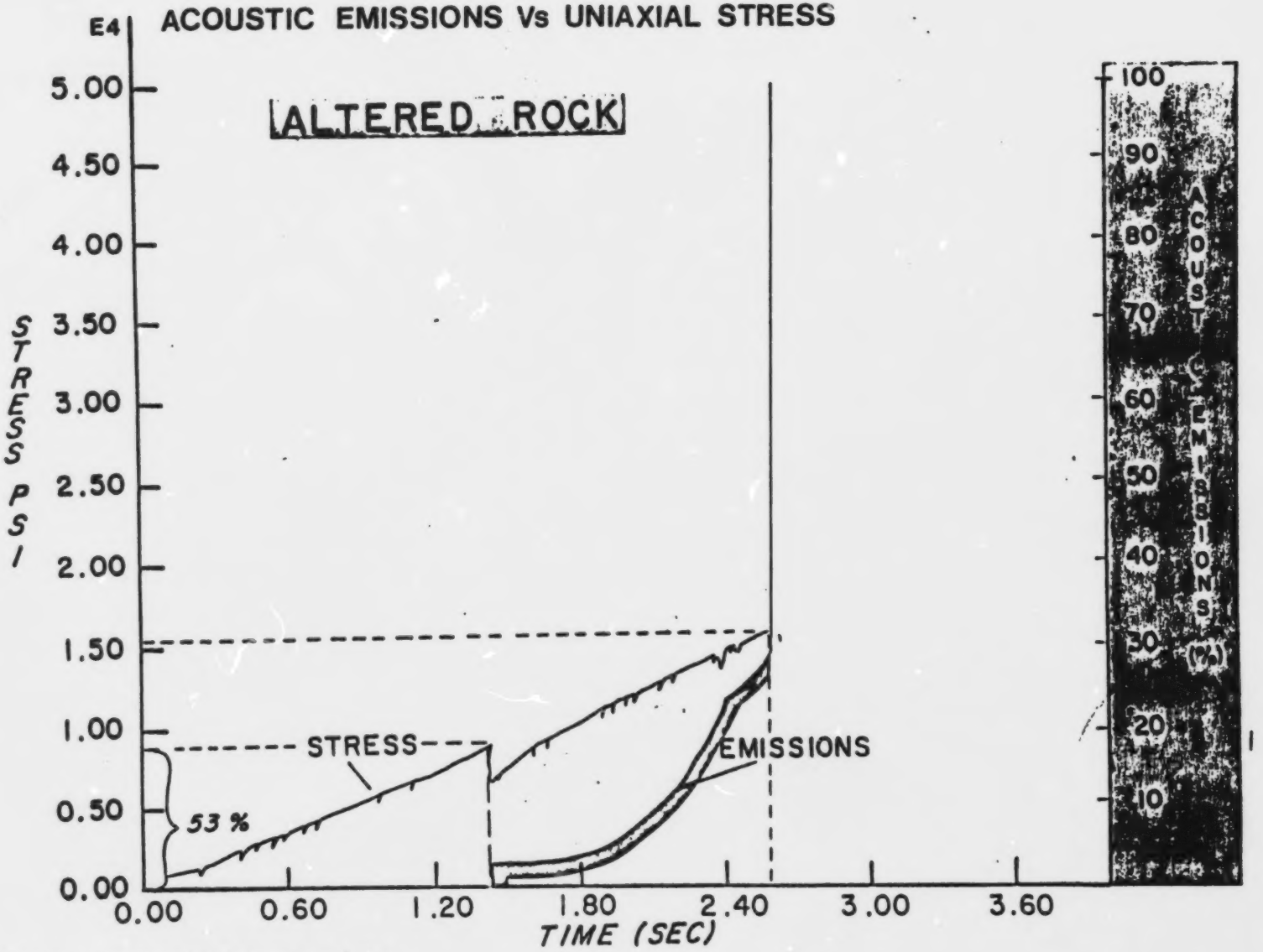

Fig. 3.5b – Acoustic uniaxial stress vs. emissions

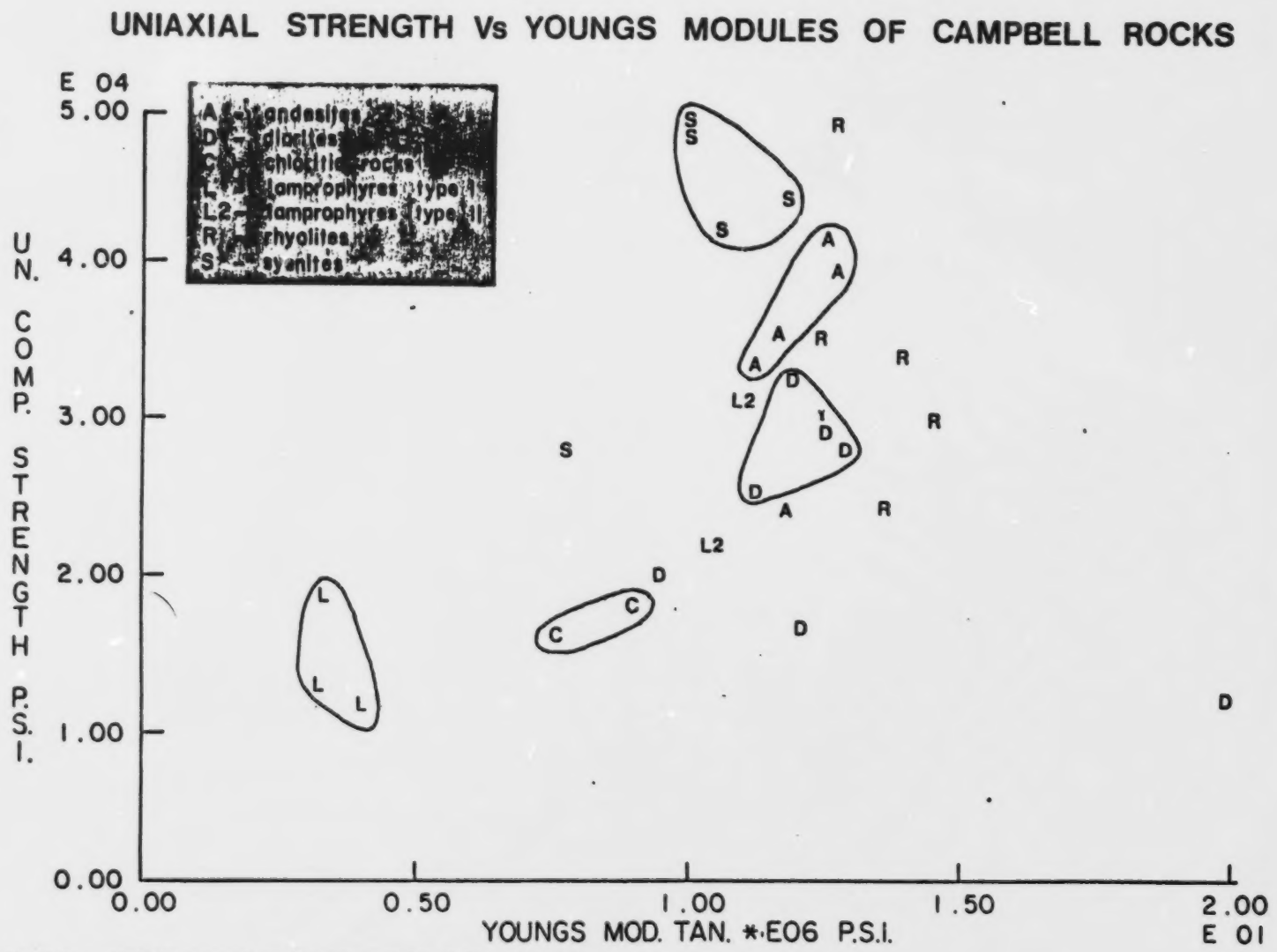

Fig. 3.5c — Uniaxial strength vs. Youngs modules of Campbell rocks

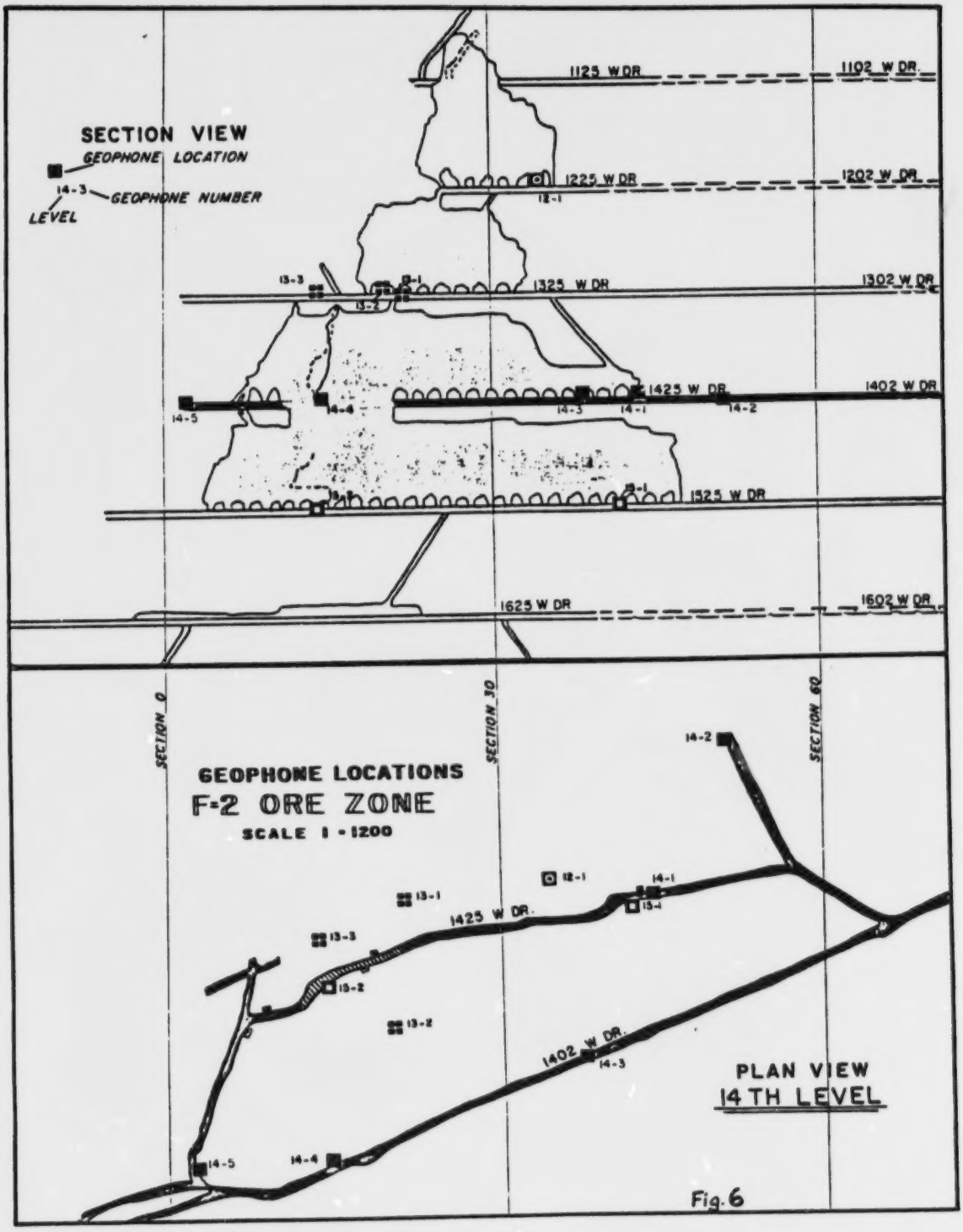

Fig. 3.6 — Geophone locations: F-2 zone monitoring

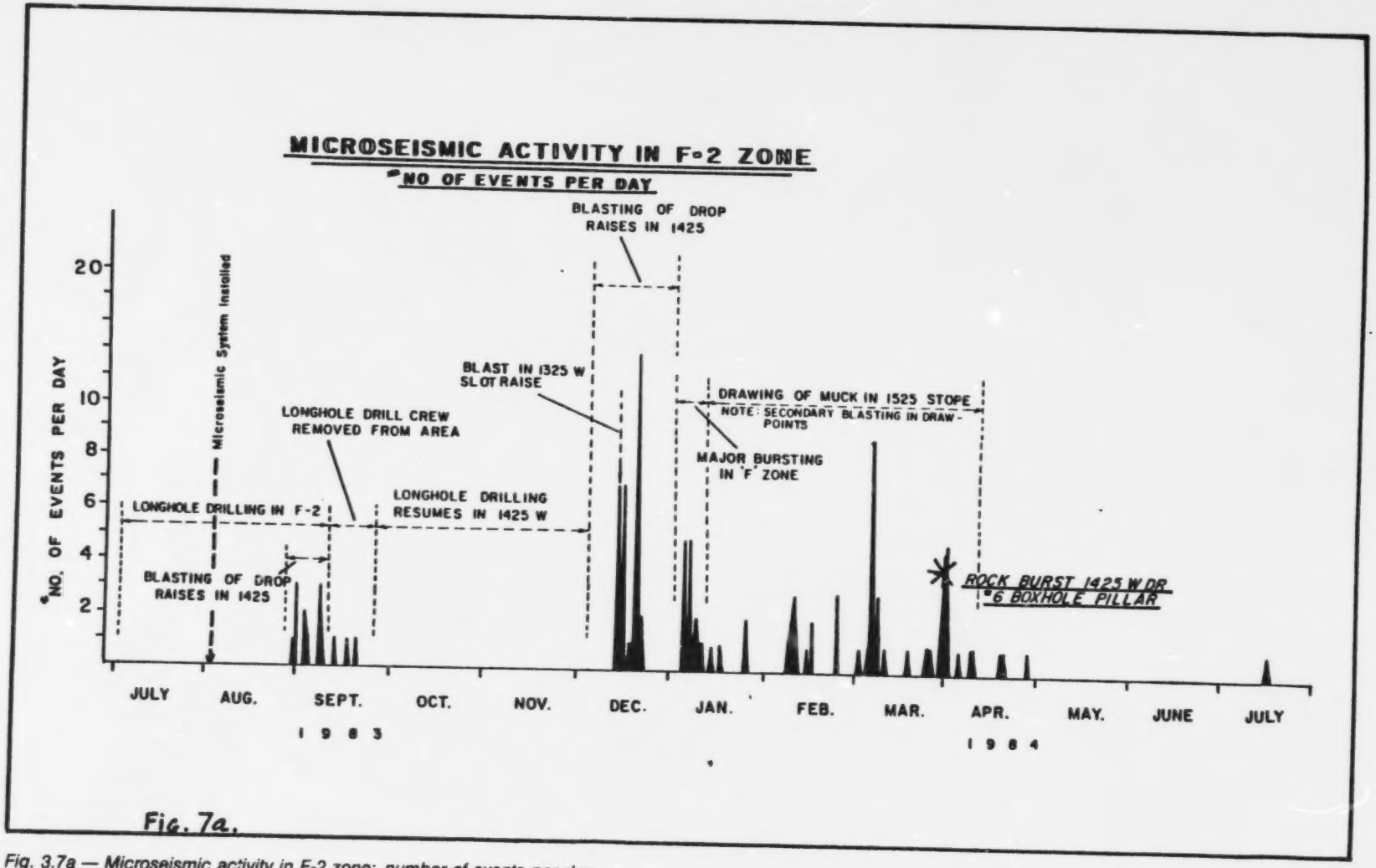

Fig. 3.7a — Microseismic activity in F-2 zone: number of events per day

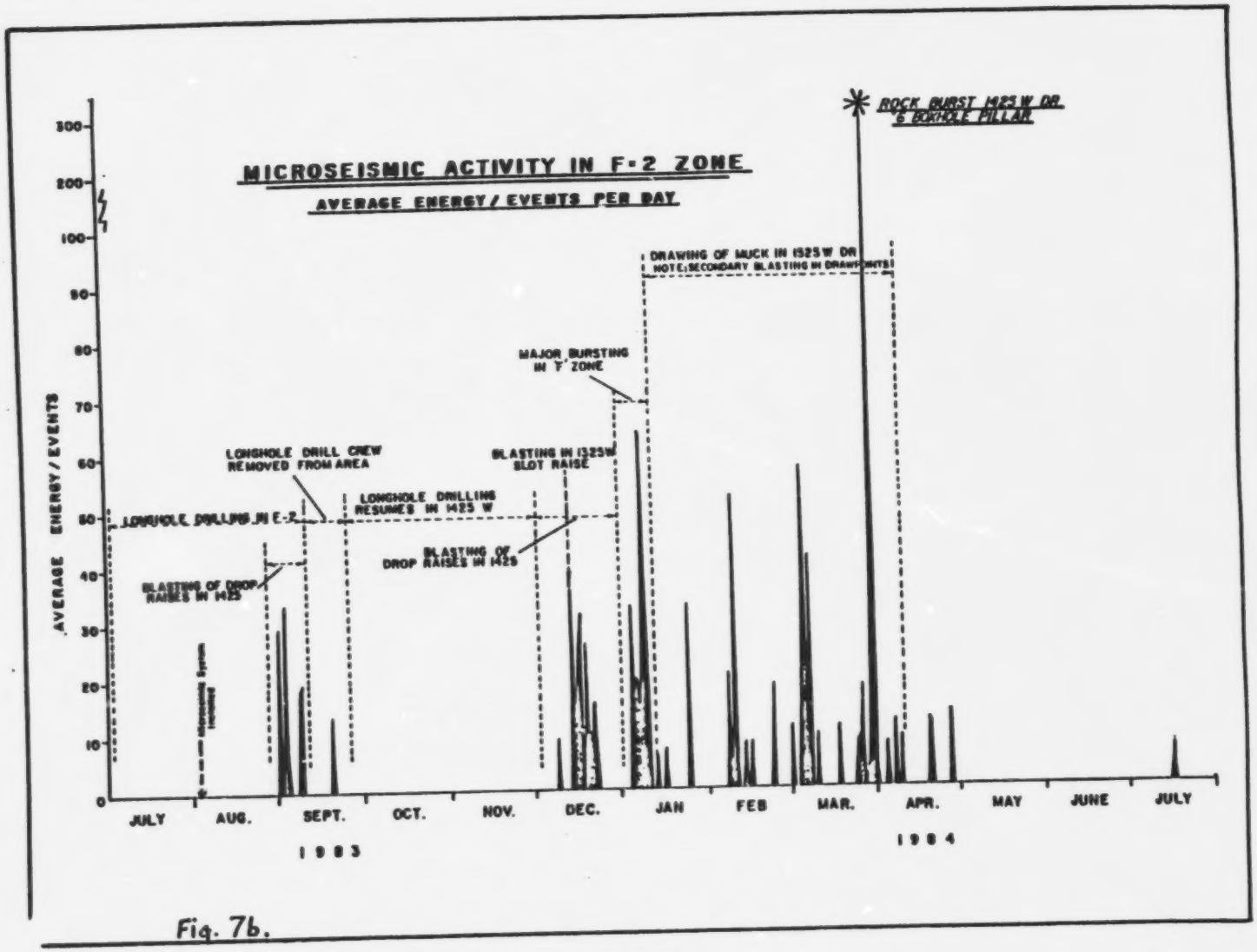

Fig. 3.7b — Microseismic activity in F-2 zone: average energy/events per day

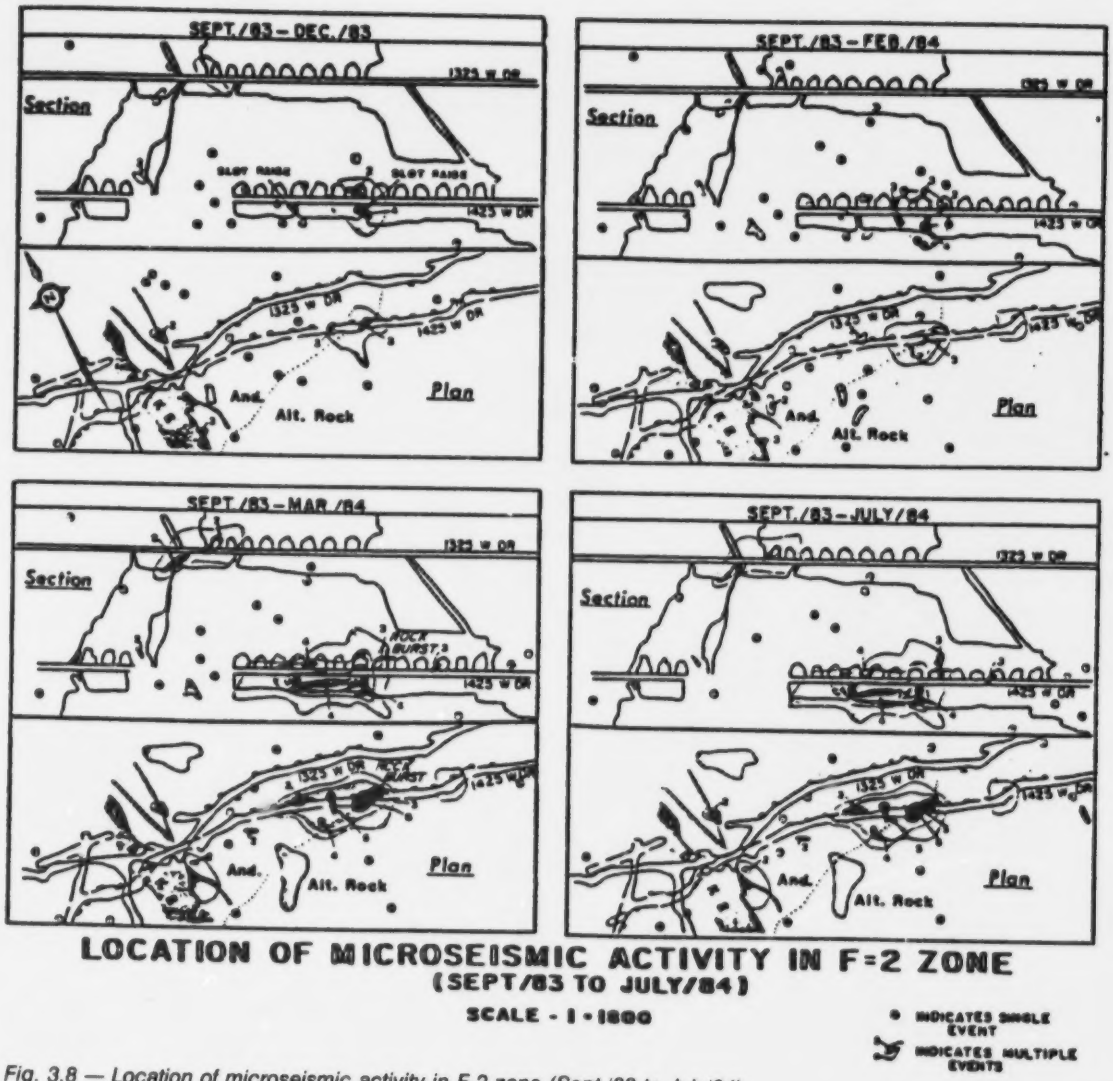

Fig. 3.8 — Location of microseismic activity in F-2 zone (Sept./83 to July/84)

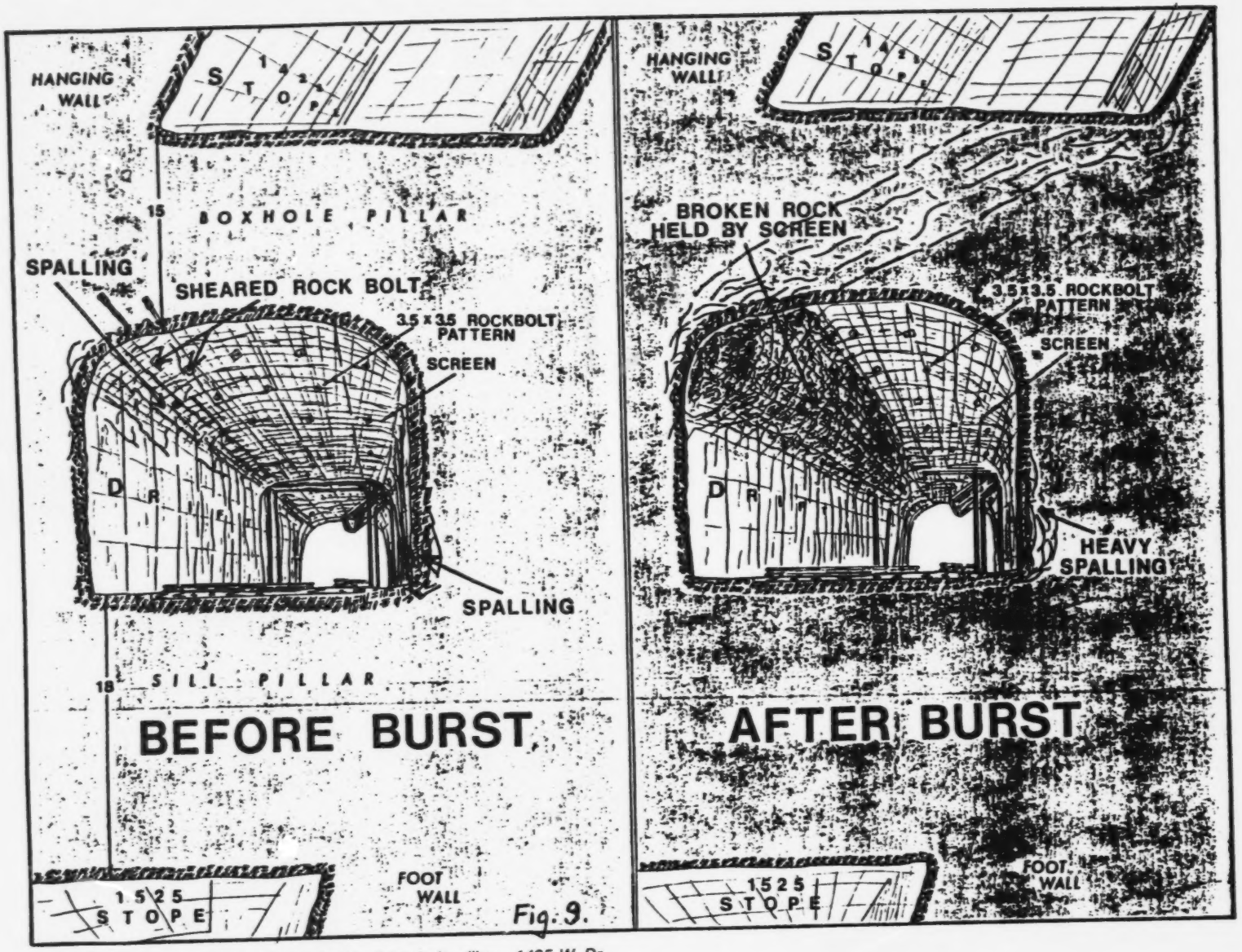

Fig. 3.9 — Recognized deterioration in No. 6 boxhole pillar – 1425 W. Dr.

SOME OPERATIONAL ASPECTS OF THE MICROSEISMIC MONITORING SYSTEM INSTALLED UNDERGROUND AT QUIRKE MINE

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ABSTRACT

Quirke Mine is the largest of the three underground uranium mines owned and operated by Rio Algom Ltd. in the Elliot Lake region of Ontario. The ore is contained in two reefs, both of which have been mined since the start of operations in 1967. However, since 1981, worsening ground conditions have been evidenced by pillar spalling, pillar failure and rockfalls, culminating in the loss of some production areas. Rock mechanics consultants, CANMET, and company personnel introduced a program for monitoring and interpreting ground movement and other data in order to establish safe and economic strategies for mining. This paper discusses the benefits of the microseismic monitoring system employed.

*Paper presented by F. Ingram, Rio Algom Ltd.

QUELQUES ASPECTS OPÉRATIONNELS DU SYSTÈME DE SURVEILLANCE MICROSISMIQUE INSTALLÉ DANS LA MINE QUIRKE

B. Eyres*
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RÉSUMÉ

La mine Quirke est la plus grande des trois mines souterraines d'uranium exploitées par la Rio Algom Ltd. dans la région d'Elliot Lake (Ontario). Le minerai se trouve dans deux récifs qui ont été exploités depuis le début des opérations, en 1967. Cependant, depuis 1981, les conditions du sous-sol se sont aggravées, ce qui s'est manifesté par l'effritement des piliers, l'effondrement de ceux-ci et par des éboulements qui ont fini par entraîner la perte de certaines zones productives. Des ingénieurs-conseils de la mécanique des roches, le CANMET et le personnel de la société ont entrepris un programme de surveillance et d'interprétation des mouvements du sol et d'analyse d'autres données afin d'établir des stratégies d'exploitation sûres et rentables. La présente communication examine les avantages du système de surveillance microsismique utilisé.

**Document présenté par F. Ingram, Rio Algom Ltd.*

SOME OPERATIONAL ASPECTS OF THE MICROSEISMIC MONITORING SYSTEM INSTALLED UNDERGROUND AT QUIRKE MINE

INTRODUCTION

Quirke Mine, Rio Algom Limited, is a uranium mine situated in Elliot Lake, Ontario. Mine production is presently 1.8 million tons milled per year with approximately 1050 employees. Quirke Mine is the largest of Rio Algom's three operating mines in the district.

The mine is entirely underground and is served by a vertical timbered shaft to the bottom level, 2260 ft from surface.

The ore is contained in two major mining reefs, the "A" Reef and the "C" Reef. The vertical separation of the two reefs is about 150 ft with the "A" Reef lying above the "C" Reef; both reefs dip at about 20 to the south. Most of the production, since the start of operations in 1967, has been from the higher grade "C" Reef; these reserves are now largely mined out and about 85% of production is now from the "A" Reef. The mining method in the "C" Reef uses jacklegs and slushers for a top slice of up to 8 ft and benching with wagon drills when thickness warrants. In the fall of 1981, an abnormal amount of pillar spalling was noticed in the 7 level sill drift over a distance of about 1000 ft. A scaling and bolting program was completed but spalling continued and a second rescaling and rebolting was completed in February, 1982.

On Wednesday March 10, 1982, significant ground movement occurred in predominantly mined-out areas of the "C" Reef, centred on the 7 level at a depth of about 1600 ft. By that weekend, the movement had caused increased pillar loading, some pillar failure and rockfalls over an area of about 1500 ft square extending from half way to 600 level down to 800 sill and footwall, all of which affected footwall access to the eastern end of the mine and some active stoping in "C" Reef.

Figure 4.1 illustrates a typical conventional stope layout.

PRODUCTION AFFECTED BY GROUND MOVEMENT

Active stoping (mostly benching) in or adjacent to the area of ground movement comprised two stopes on 9 level, nine stopes on 10 level and five stopes on 11 level. The total ore reserves in the affected area were 535 000 t on above-average grade containing approximately 1.6 million lbs of U_3O_8.

ACTION TAKEN

1. Production in the "C" Reef was stopped on 7, 8, and 9 levels and crews relocated to other areas. The production lost was about 17% of mill throughput at the time, but, because of the above-average grade, this represented about 25% of uranium production and was not easily replaced.
2. CANMET, with an organization in Elliot Lake, provided services.
3. Rock mechanics consultants were employed.
4. Geophone and convergence metres were installed.
5. Daily foot patrols were established to monitor affected workings and provide interpretation of micro-seismic and other data.
6. Union representatives were kept continuously informed.

Figure 4.2 shows the eastern sector of New Quirke, "C" Reef. A major airway was located through the centre of the area. The ore reserves mined after March, 1982, are shaded. The increase in the area of disturbance can also be seen.

ORE RECOVERY IN THE AFFECTED AREA

Various studies were made by rock mechanics consultants, CANMET, and, in-house, by Rio Algom engineering staff. The rock mechanics data and stresses were evaluated, and a plan was devised which involved the installation of stress metres and the geophone array.

The mine planning people evolved an ore extraction plan and developed a strategy for mining. The continuing operation of the instrumentation during the mining phase facilitated the safe recovery of 350 000 t of high grade ore from the original ore reserve tonnage of 535 000 (which is 65%).

BENEFITS OF THE MICROSEISMIC MONITORING SYSTEM

Monitor Effects of Blasting

All blasting operations are recorded by the microseismic monitoring system.

Security of Access

Prior to the start up of the shift, a printout is available which informs the production supervisors as to the location, intensity, and time of any seismic event recorded by the system. This assists the supervisor to make decisions regarding the placement of the oncoming shift, and to direct the observation crew to the site of any events.

Security of Production

The decisions made by management to ensure continuity of production are based on many parameters. The additional data available arising from the installation of the geophone array creates a scientific base from which greater confidence in the decision making process is created.

Stability of Airways

All mines have major arteries, such as shafts, airways and conveyor ways that require special protection. At Quirke Mine, the major airway in the vicinity of the ground movement was the cause for concern. The installation of the microseismic monitoring system enabled management to continually monitor any encroachment of instability towards the main airway.

Location of Events

The microseismic monitoring system locates the area affected by seismic events with an adequate degree of accuracy. The advantages of good location are that an examination of the affected area may be undertaken without undue delay, and the safety of men working in adjacent working areas will not be compromised.

The location of events enables the microseismic monitoring team to correlate the data, and examine and report on trends which may be occurring.

Future Planning

The future planning of mining, to extract the maximum ore at the minimum cost, is facilitated by the installation of the microseismic monitoring system.

The calculations of safety factors for pillars and extraction ratios is more scientifically calculated, making good design and safe extraction of the ore reserves possible. At Quirke Mine, 65% of the ore in the affected area was safely mined.

Foot Patrols and Supervision

The continuous monitoring of the affected area by foot patrols was stopped after the geophone system was installed. The inordinate amount of the senior supervisors' time underground in the affected area was no longer required.

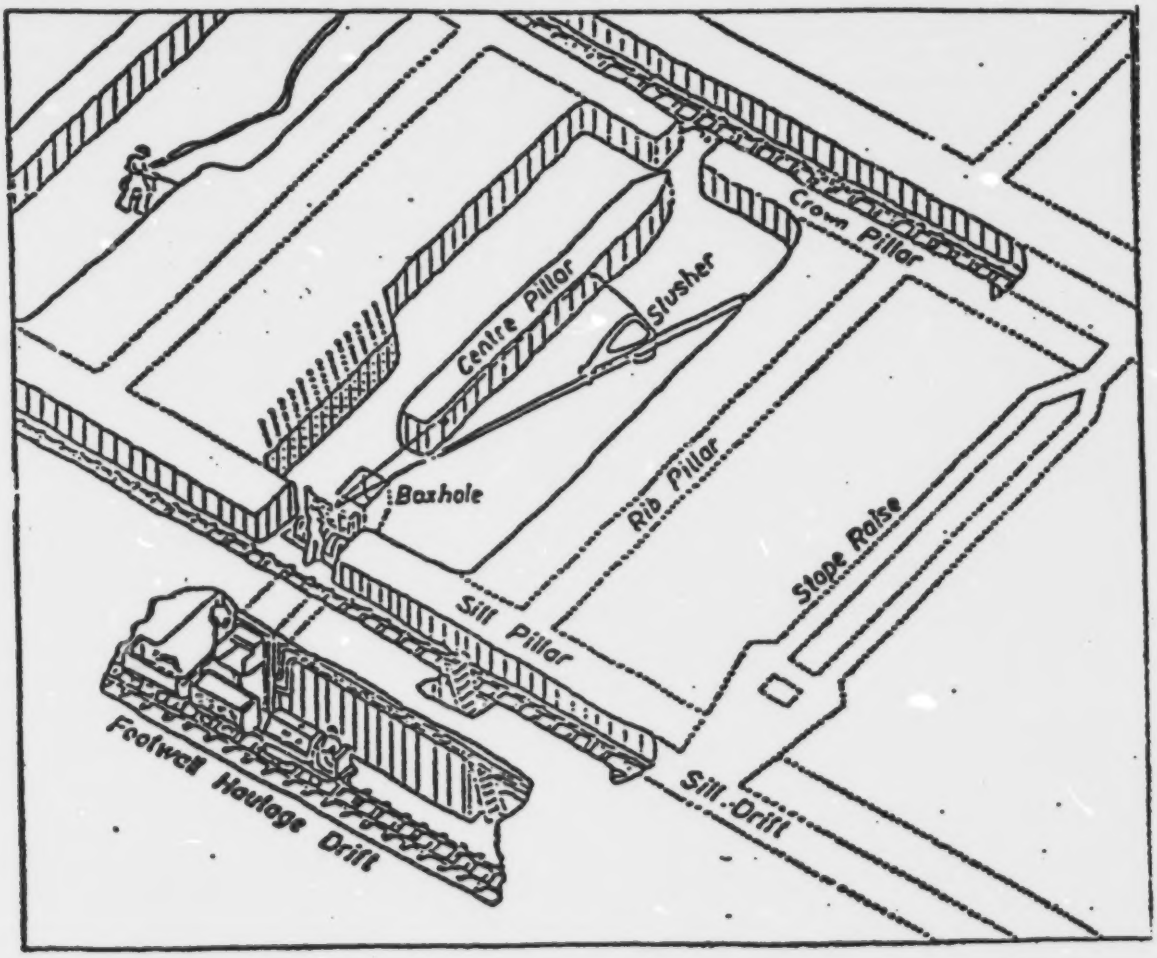

Fig. 4.1 — Layout of conventional stope

Notes:

1. Each stope has two panels of 60 ft width separated by 15 ft wide pillars on dip and crown and sill pillars at vertical level intervals of 154 ft. Boxholes at 150 ft intervals are connected to track bound footwall haulage drifts. Single pass ventilation is achieved by directing fresh air from the footwall haulage to the sill drift in the level above. Service access is by the sill drifts.
2. The standard layout represents an extraction level of 84% but, in the area of failure, pillars were left a little wider in the bench. Some pillar recovery was planned on retreat and had been completed in some areas east and north of the affected area.
3. Production from these stopes was up to 3000 tons/month, per stope.
4. A stope crew consisted of three men, two drilling and bolting one shift, and a slusherman on the cross-shift.
5. Back support is by 6 ft conventional shell bolts at 4 ft centres.

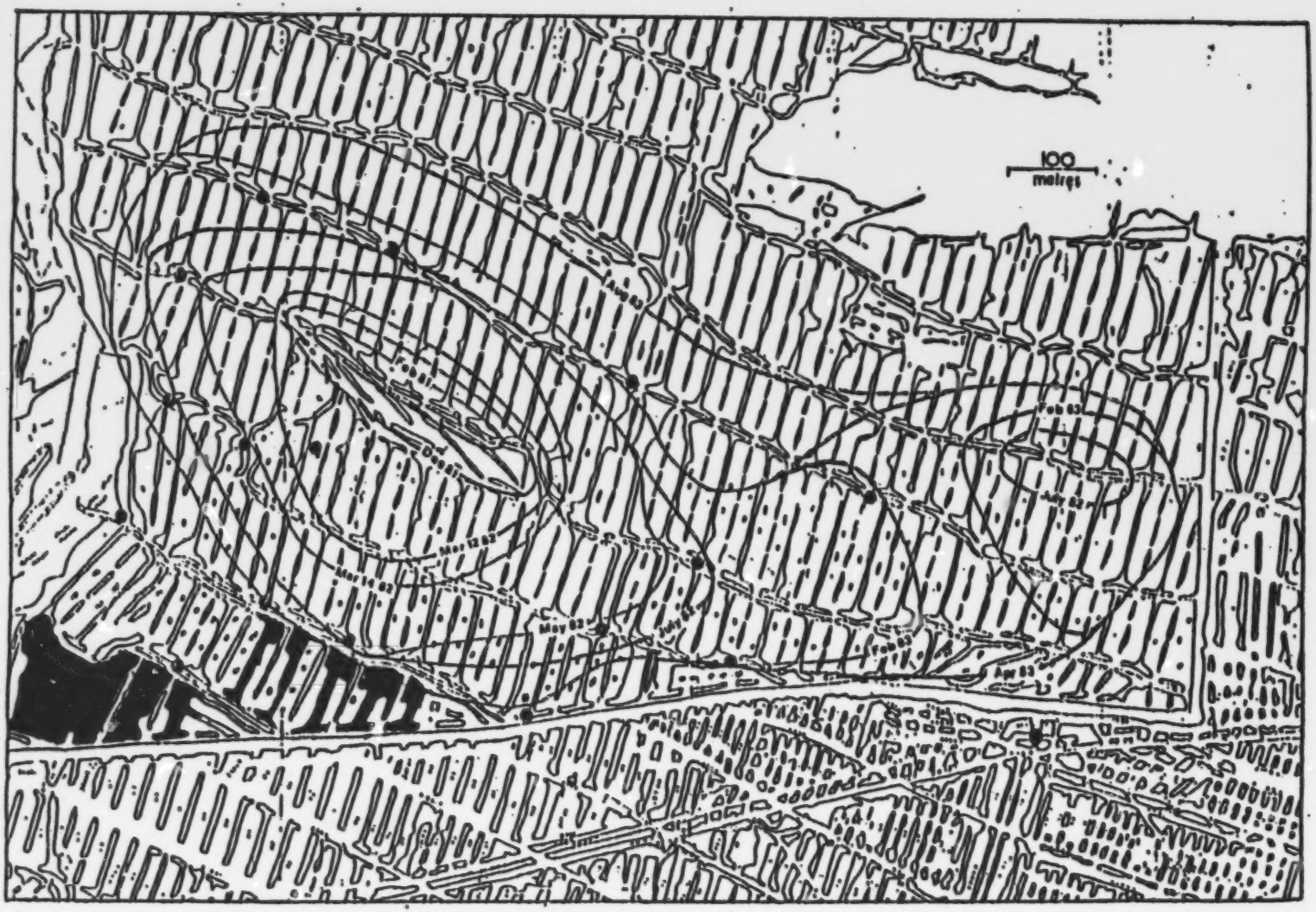

Fig. 4.2 — Eastern sector, New Quirke Mine, showing ore reserves, geophone array, and expansion of affected area

DISCUSSION

J. Bourbonnais: Have you been able to tie in your convergence measurements with the microseismic activity?

F. Ingham: Yes, very well. Due to deterioration of the access drifts, most results apply to the periphery of the rockburst area; however, measurements of accelerated movement coincided with microseismic activity. There were approximately 52 convergence stations at the last count, mainly in stope cut outs, and one technique enhances the other. Stations have been lost in the centre of the rockburst area, due to inaccessability or being hit by loose.

T. Yu: How long was the area affected by rockbursts closed down?

F. Ingham: The area affected by rockbursts was mined out, except for a few stopes on two levels down dip of the centre of the zone. These stopes were closed down while a rock mechanics assessment was conducted, instrumentation installed and new production plans developed.

T. Vladut: Please give more details about conditions prior to the major events.

F. Ingham: Spalling on the top up-dip corner of the sill drifts and cracking on the bottom down-dip corner occurred at an early stage. Progressive degradation and bursting resulted in some drifts becoming completely inaccessible.

B. Smith: Are you satisfied with the accuracy of the source locations evaluated by the MP-250?

F. Ingham: With the planar nature of the orebody we are not sure what effect reflections have on location accuracy. In addition, the orebody is heavily faulted. Tests indicated that average accuracy is 100 ft in the plane of the orebody within the array. This is acceptable bearing in mind the faulting and that the orebody is largely mined out in the area.

H. Kanduth: What was the result of installing geophones off the plane of the orebody?

F. Ingham: Concern about caving through into the upper reef (150 ft above) meant that vertical resolution was important. One geophone was installed 200 ft down a surface diamond drill hole. It hasn't given us much more vertical accuracy and there have been problems with the detector.

* * *

EVALUATION OF THE McPHAR MODEL RM-1 ROCK MONITOR

B.J. Welsh
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August 1984

ABSTRACT

From September 1982, until the present time, Dickenson Mines Ltd. has used the "Stress Alert" Rock Monitor, model RM-1. As a warning device, it has proved to be ineffective in predicting ground instability, rock failure, or rockbursts. Disadvantages include frequent equipment malfunctions, and a limited measuring range. However, in two situations, presented in case studies, the Rock Monitor did appear to record elevated 'stress factor' measurements in areas which were known to be undergoing increased levels of stress. Therefore, there may be the possibility of using the Rock Monitor as a monitoring tool for:

1. Evaluating the stability of an area which has undergone rockbursting, before resuming mining.
2. Evaluating the effectiveness of a distressing program or a ground support system, such as cable bolts or swellex bolts.
3. Supplementing other forms of monitoring for measuring stress changes.

ÉVALUATION DU MONITEUR RM-1 – MODÈLE McPHAR

B.J. Welsh
Dickenson Mines Ltd.
Août 1984

RÉSUMÉ

De septembre 1982 à aujourd'hui, la Dickenson Mines Ltd. a utilisé le moniteur "Stress Alert", modèle RM-1. En tant qu'appareil avertisseur, il s'est révélé inefficace dans la prévision de l'instabilité du sol, de l'effondrement des roches ou des coups de charge. Les inconvénients de cet appareil sont la fréquence de ses anomalies de fonctionnement et sa plage limitée de mesure. Cependant, dans deux situations, présentées dans les études de cas, le moniteur semble avoir enregistré des mesures élevées du "facteur de contraintes" dans des zones où l'on savait que les contraintes augmentaient. Il serait donc possible d'utiliser l'appareil comme outil de surveillance pour:

1. Évaluer la stabilité d'une zone qui a subi des coups de charge, avant de reprendre l'exploitation.
2. Évaluer l'efficacité d'un programme de réduction des contraintes d'un système de soutenement de terrain, tels que le boulonnage par câble ou le boulonnage swellex.
3. Établir d'autres formes de surveillance afin de mesurer les variations des contraintes.

EVALUATION OF THE McPHAR MODEL RM-1 ROCK MONITOR

INTRODUCTION

In March of this year, Dickenson Mines Ltd. was asked by Mr. Paul MacDonald, a research scientist with CANMET, to submit a presentation on a high-frequency microseismic rock failure warning system. The system is sold under the commercial name "Stress Alert", or Model RM-1 Rock Monitor, available from McPhase Mine Systems Inc., of Willowdale, Ontario (Fig. 5.1).

Dickenson obtained the Stress Alert Monitor, Linseis Chart Recorder, and Remote Warning Flasher in 1982 under a 12-month rental/purchase agreement. After completion of the 12-month period, it was felt that the purchase option was the most practical course of action because of the amount of money already spent up to that point. The unit has been tested extensively over the past two years at Dickenson, and a brief summarization of results, with two case studies, is presented in this paper.

Paul MacDonald has adequately described the Rock Monitor in his paper released in January of this year, and his testing of the unit in three other Ontario hardrock mines has been extremely helpful to me in preparing this paper.

APPROACH

Monitoring Record: September 1982 to August 1984

From September 28, 1982, until the present time, the Rock Monitor has been used in a total of five different areas, for extended periods of time. The chart below lists these locations and dates. For most of this time, panel controls were maintained, as recommended by the manufacturer, at the following settings:

Gain	= 80 db	
Trig Level	= 35 – 0.55	(where required to filter out interference)
Paper Advance	= 2 cm/h	
Measuring Range	= 2V	
Gain Control	= "var"	

These settings were suggested in order to filter out extraneous noise, such as drilling or blasting, although that turned out not to be the case. It should be noted that threshold values are set too high for "events/min" and consequently screen out virtually all measurements, as normal background levels are an order of magnitude less than the threshold level. The "ΔS", or "stress factor" threshold was, in fact, at a reasonable level, and some records appear to be valid. However, these threshold limits are a major weakness of this instrument when operated in hardrock mines, as well as its limited frequency range.

STRESS ALERT LOG RECORD: SEPTEMBER 1982 TO AUGUST 1984

Effective dates	Location	Control settings	Purpose/remarks
Sept. 28, 1982 – Oct. 8, 1982	18-1361 B#2 H/W west	Gain = 80 dB Trig = 0.5 Range = 2 V	– monitor longhole mining
Oct. 12, 1982	5-4855 E. Dr.		– monitor 100'-wide cut and fill stope below (– no recorded activity during this time)
Oct. 25, 1982 – July 29, 1983	18-1361 #1 R stope		– monitor area of troublesome ground conditions, very burst prone
Aug. 2, 1983 – April 2, 1984	17-1155 Al		– monitor longhole sill recovery
July 24, 1984 – present	16-1583 E. Dr.	Gain = 90 dB Trig = 0.25 – 0.40 Range = 500 mV	– monitor highly-stressed squeezing, smapping ground

Fig. 5.2 — Tabulation

Case Study #1: 18-1361 No. 2 R. stope, October 1982 – July 1983

Between October 25, 1982, and July 29, 1983, the Rock Monitor was placed in 18-1361 No. 2 R Stope. This stope has what could be termed "difficult" ground conditions, which have since been controlled by an extensive program of cable bolting, destressing, crib sets and timbering, and bolting. Historically, it has been a very burst-prone area, subject to at least fourteen major bursts. ("Major" meaning heard throughout the mine and/or in the townsite, and accompanied by a significant amount of damage or rock displacement).

During this time, the Rock Monitor experienced numerous malfunctions, and a progress report issued on it in November 1982 is contained in Appendix A.

The map and longitudinal in Fig. 5.3 illustrates where the monitor was located and where mining was taking place at that time.

Case Study #2: 16-1583 E. Dr., July 1984 – August 1984

On Friday, July 24, 1984, the Rock Monitor was placed in 16-1583 E. Dr., about 1 1/2 levels above 18-1361 No. 1 R Stope where large rockbursts occurred earlier this year. Immediately above the site are long, open shrinkage stopes, and there are a number of observations that point to the fact that the area is undergoing a great deal of stress. During a period of two weeks prior to the installation of the Rock Monitor, the drift showed widespread, small-scale sloughing from the walls and signs that gradual *creep* was occurring along a

pronounced fault located about 300 ft to the west of the monitoring site. This fault was the site of a violent rockburst that occurred many years ago, when a timber bulkhead was blown off the top of the raise that breaks through to a level here. The fault opened up approximately 6" to 1 ft at that time, and sloughing observed recently indicates that movement has occurred since.

Just to the east of where the rock monitor is located, cross timbers have been squeezed until broken, and in a stope located 400 ft to the east, the ground emits loud snapping and cracking noises following blasting. Initially, the stope undercut a north cross-cut – with only an eight-foot thick sill – but on July 31, this was broken through. Presently, the ground has become quiet again, no further sloughing has been observed, and the stope breakthrough appears very stable.

The map and longitudinal section in Fig. 5.4 illustrates this area, and some pertinent geological features.

Every two to three days control settings were varied to see if better resolution of data could be achieved; however, the most favourable were as follows, and the settings were for the most part kept constant at these levels so that comparison of data could be done:

Gain	:	90 dB
Trig Level	:	0.40
Paper Advance	:	2 cm/h
Measuring Range	:	500 mV

On July 27, the measuring range for "# events/min" was lowered to 50 mV, to see if that would increase the sensitivity and hence lower the threshold limit, but there was no noticeable change.

During the week of July 24-31, elevated levels of activity were recorded, around 100-200 event/min, with the energy level/event around 55-60. For no apparent reason, on Sunday, July 29 at around 8:30 p.m., the readings dropped to zero. An instrument malfunction would have been presumed, but there was also a marked reduction in audible rock "noise", and the ground appears to have settled down. I have no clear explanation for this apparent quiescence, and it doesn't appear to be due to the usual period of quiet prior to violent bursting, since the pressure on cross timbers appears to have relaxed somewhat.

RESULTS

General

While being used in the A.W. White Mine from September 1982 to August 1984, the Rock Monitor failed to record any major rockburst or indicate in any way that any event had occurred although at least seventeen events were known to have occurred during that time period. The following chart lists these.

In addition, the vast majority of the chart records produced were simply flat (zero reading) pen traces, and hence useless as indicators of changing rock stress or ground activity. The two case studies presented are the only examples where the Rock Monitor did seem to be reacting to ground conditions. Only the pen recording the *stress factor*, or the relative *energy level per event* ever reacted. The pen recording the *number of events per minute* never left the zero mark because of the high threshold level setting.

Case Study #1: 18-1361 No. 1 and 2 (R) stope

Referring to the chart records on November 2-3, 1982, elevated activity levels were recorded, and this corresponded to a great deal of 'snapping and popping' noises heard in the stope. However, chart records weren't consistent, and it is difficult to draw conclusions from them.

For example, on November 2, 1982, a longhole blast, located 50 ft from the instrument, may have been picked up, as there was a relatively isolated peak at that time. Alternatively, the instrument may have been recording ground activity generated by the blast, since there was more than one peak coinciding with the blast time. As well, the next day, three peaks coincided with a reblast. However, none of these peaks were outstanding, and the most notable activity occurred from 7:00-11:00 p.m. on November 2, and from 4:00-5:30 a.m. on November 3. During this latter period, a very high stress factor reading was made, but no rockbursts were reported at that time.

Date	Time	Location	Rock Monitor location	Remarks
(None recorded during 1982)	———	———	18-1361 #2 H/W west	no significant readings
April 27, 1983	3:30 p.m. – 7:30 a.m.	17-1155-Al sill		not recorded
June 29, 1983	3:00 a.m.			heard on surface, not recorded
June 30, 1983	7:00 a.m.			
July 2, 1983	11:20 p.m. – 12:05 a.m.		—	
Aug. 20, 1983	?	party wall-SC zone	17-1155-Al sill	anomalous stress readings, no correlation to bursts
Aug. 20, 1983	10:20 p.m.			
Dec. 15, 1983	10:30 a.m.	6-4655 stope		
Dec. 29 to Jan. 4, 1984	———	Campbell RLM "F" zone		some heard 10 miles away, none recorded
Jan. 25, 1984	9:00 a.m.	15-1458 E. Dr.		not recorded
Feb. 1, 1984	6:10 a.m.	18-1361 #1 R. St.		heard on surface, not recorded
June 18, 1984	1:30 p.m.	23-13120 St.		only localized bump, not recorded
July 8, 1984	9:30 p.m.	18-1361 #1 R St.		heard on surface, not recorded
July 17. 1984	10:00 a.m.	23-10120, 13121 St.		only localized bump, not recorded
July 21, 1984	10:40 p.m.	?	—	heard on surface, not recorded
July 24, 1984	? (N/S)	25-1298 St.	16-1583 E. Dr.	only localized bump, not recorded
July 26, 1984	9:13 a.m.	11-1655 E. Dr.		heard on surface, not recorded
July 27, 1984	1:15 p.m.			
July 31, 1984	3:15 a.m.			

On March 25, 1983, three periods of elevated activity were recorded, around 1:00-4:30 a.m., May 20. In between these active periods, the Rock Monitor recorded virtually zero activity. A blast at 3:00 a.m., May 20, did not register significantly above the already elevated activity level at that time, although it was located only 65 ft away. However, a period of moderate activity was recorded for 5-6 h after the blast (not present when no blasting occurred), which may represent the ground "working' following the blast.

Whether these records correspond to significant ground activity, or tell us anything about how the ground is behaving is difficult to say, since for these examples, no one was actually present by the machine to gather corroborating evidence at the same time records were being made by the instrument. However, the Rock Monitor was placed in an active area, and changes were noted in the readouts, although it is not clear what these changes actually meant. The alarm proved to be extremely unreliable, as mentioned in the progress report contained in Appendix A, and equipment malfunctions were frequent.

Case Study #2: 16-1583 E. Dr.

Once more, the Rock Monitor was placed in an area in the mine where a lot of activity was occurring, including audible noise and visible sloughing, as well as three major rockbursts and two small production blasts. The Rock Monitor failed to record, or show indications of stress changes as a result of the three rockbursts, which were located at the Campbell Red Lake Mine boundary, or as a result of blasting in a stope located 400 ft away.

This is what would be expected, since testing done by Paul MacDonald (Jan. 1984) has shown that the range of the instrument is less than 82 ft (25 m). However, the immediate area was undergoing stress, and the monitor showed an elevated stress factor during periods when audible noises were heard in the drift and in 17-1155 No. 1 and 2 (R) stope. When activity stopped temporarily in the stope, the Rock Monitor showed a zero readout. When ground activity resumed on August 2, 1984, with a small rockburst occurring in the footwall of the stope, heightened activity began to show again on the Rock Monitor.

These results are far from being quantitative, and interpretation of changes is very uncertain, since some of the reduction in activity can be attributed to loss of battery power. Also, when fresh batteries are installed, falsely elevated readings occur, and 2-3 hours are required before these settle down. After 2-3 days of operation, the Lithium Sulphate sensor shows a reduced sensitivity, but it is not clear whether this reduction in activity is due to battery loss or actual settling down of rock activity. Nonetheless, when the readout dropped suddenly to zero on July 30 there was a definite reduction in activity in 17-1155 No. 1 and 2 (R) stope, as well as a relaxation in cross-timbers in an old shrinkage stope immediately above the rock monitor.

DICUSSION AND CONCLUSIONS

During the entire two year period that Dickenson has used the Rock Monitor, it has never detected a rockburst, to the best of our knowledge. The limited range of the instrument makes the likelihood of it doing so very slight indeed. Important limitations of the instrument, in addition to this limited monitoring range are:

1. The very high resonant frequency of the lithium sulphate crystal sensor causes it to screen out a very important portion of the seismic wave, since the high frequency portion is too easily refracted or attenuated underground.
2. The sensor is unidirectional, again limiting reception.
3. Threshold limitations are set too high for recording a large number of events, and there is no access for modifying this setting.
4. Low reliability, especially in terms of power supply. As well, with the number of components required underground (batteries, recorder, sensor and mount, warning light, cables, and the RM-1 unit itself), the potential for malfunctioning equipment is unusually high.
5. The warning light is inappropriate for use in hardrock mines, and has not been adapted properly from softrock mines, leading to numerous failures and false alarms.

However, the Rock Monitor may not be without some merit as a tool in monitoring stress changes. The two case studies have shown that the Rock Monitor reflects ground activity in some way; therefore, some important applications of the instrument are possible:

1. To evaluate the effectiveness of a destressing or cable bolting program, or other good support system.
2. To supplement other forms of monitoring to determine which areas are undergoing stress changes.
3. To help to ascertain whether work can resume in an area which has undergone rockbursting.

It should be kept in mind, though, that there is no way of knowing what the recorded patterns represent (for instance, what stage or state of fracturing that is occurring), and insufficient research was done before introducing the instrument for use in hardrock mines, so very few of the initial advertising claims can be met. (These have been modified considerably with time, as can be seen in the literature contained in Appendix B)

The instrument has some possibility as a monitoring tool for well-defined problem areas of limited extent, but results are quite vague, and a certain amount of judgement should be exercised.

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7. "RM-1: case histories and applications"; McPhar Mine Systems, Inc.

Fig. 5.1 — McPhar Stress Alert Rock Monitor, Model RM-1

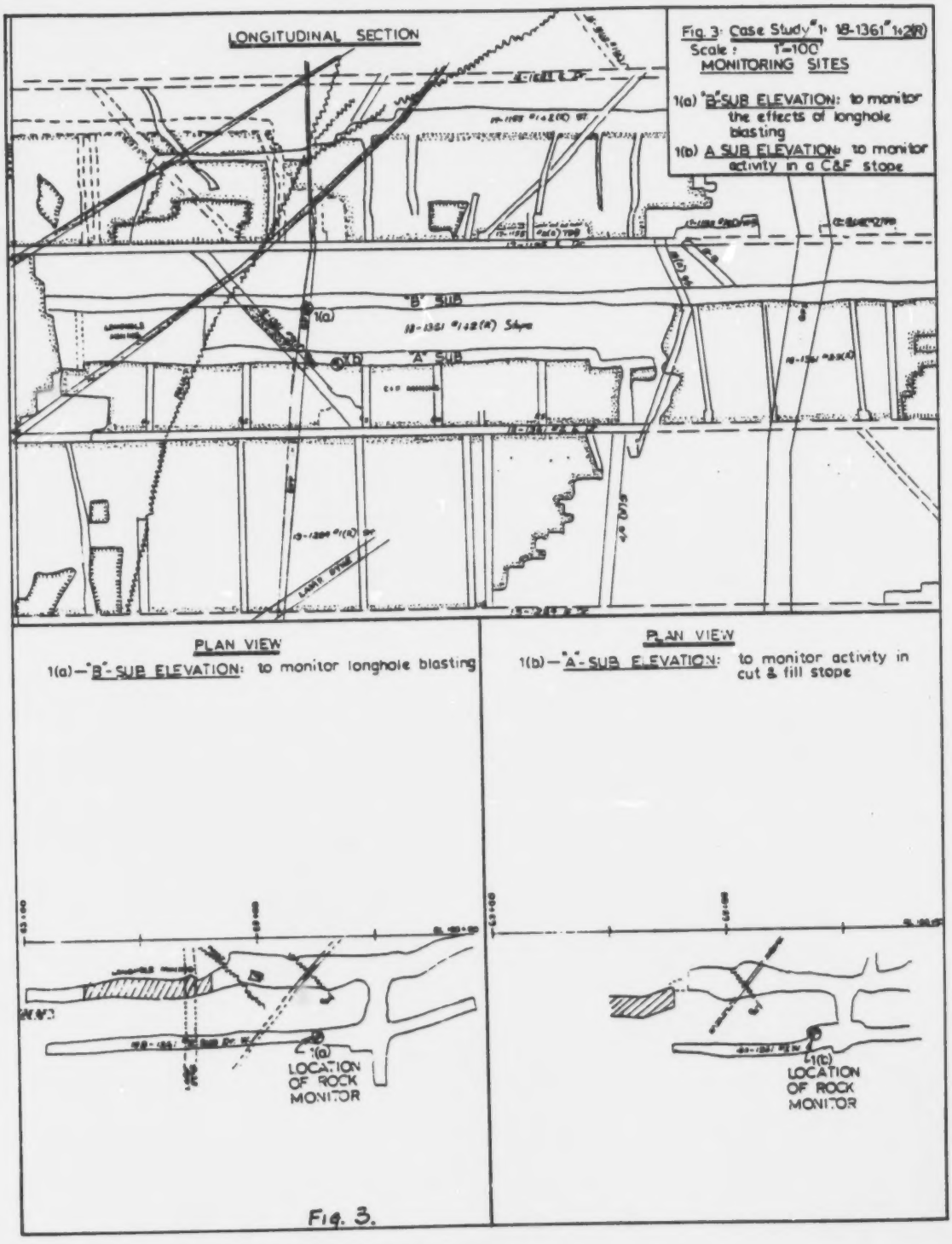

Fig. 5.3 — Case study #1: 18-1361 No. 1 & 2 (R) stope

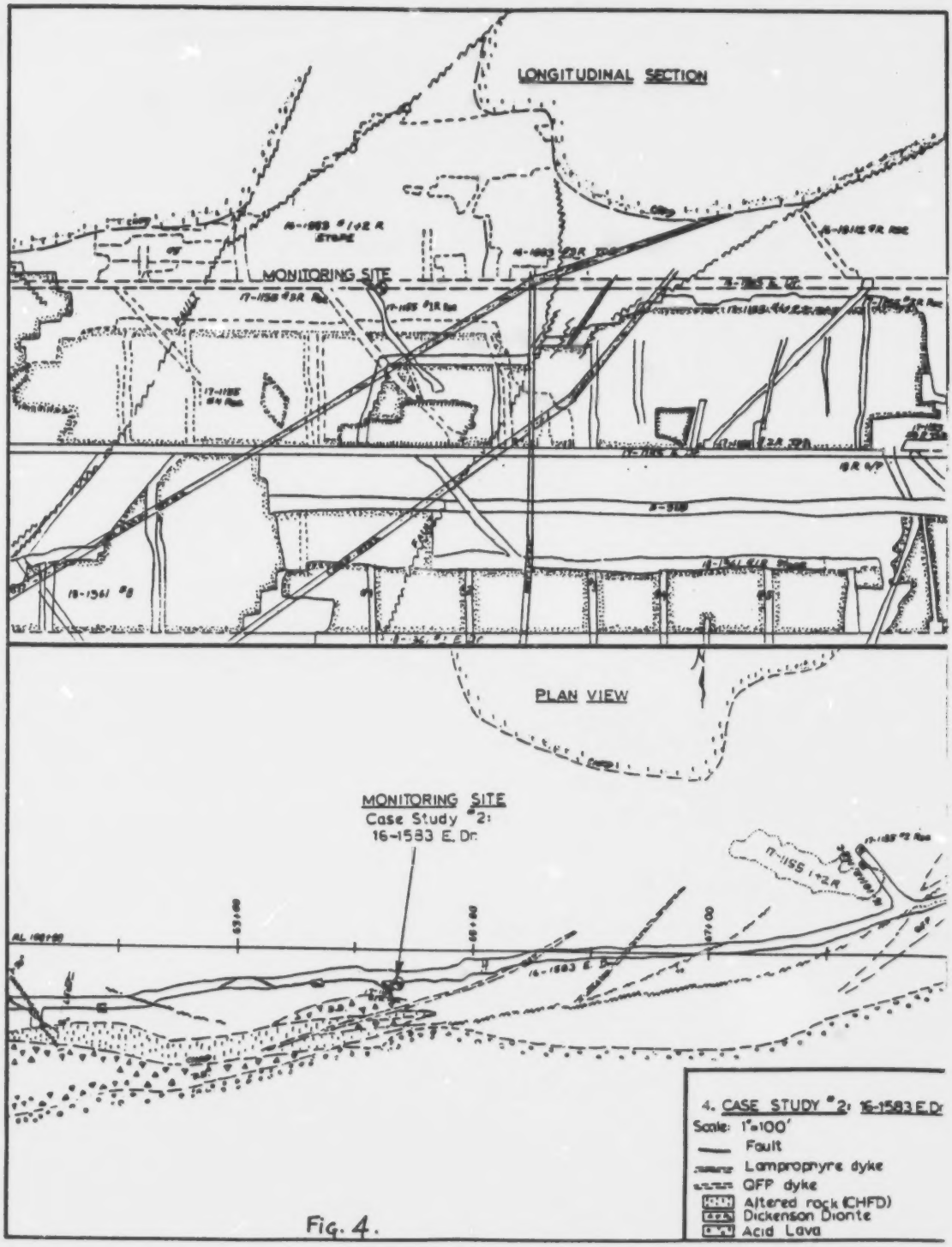

Fig. 5.4 — Case study #2: 16-1583 E. Dr.

APPENDIX A

DICKENSON MINES LTD. PROGRESS REPORT

ON STRESS ALERT, NOVEMBER 16, 1982

Inter-Office Memorandum
Date November 16, 1982

Subject: PROGRESS REPORT ALERT MONITOR

During the past month the monitor has been installed in 18-1361 B Sub to monitor the reaction from longhole blasting. There was one small suspected rockburst but the monitor alarm did not go off. On another day the alarm went off and there was no rockburst. After talking to the designer, Carl Fisher, about some of the high stress readings we were getting on the recorder, he suggested that we set the trig level higher. This we did.

We were not able to have the reactor installed at the time due to short battery life. We have just received an external battery hook-up which should give us continuous recording. One problem encountered was the recorder tape jamming; we hope to rectify this.

McPhar is still working on a remote warning device and we hope to have this soon.

RR:vr

EVALUATION OF THE "STRESS ALERT" ROCK STRESS MONITOR IN NORANDA GROUP MINES

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ABSTRACT

The occurrence of rock falls and rockbursts continues to be a major problem in the mining industry and in recognition of this the industry has always searched for means to identify unstable areas so that action can be taken to either prevent ground failures or evacuate working areas before collapse occurs. Acoustic emission monitoring systems are just one of the tools that rock mechanics engineers can use, and the Mining Technology Division of the Noranda Research Centre undertook an evaluation of a new instrument known as the "Stress Alert" Rock Stress Monitor (RSM). The results of this evaluation are presented in this paper.

ÉVALUATION DU MONITEUR "STRESS ALERT" DANS LES MINES DU GROUPE NORANDA

H. Kanduth
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Division de la technologie minière

RÉSUMÉ

Les éboulements de roches et les coups de charge continuent à beaucoup préoccuper l'industrie minière; afin d'y remédier, cette dernière a toujours cherché des moyens pour localiser les zones instables de façon à agir, soit en empêchant les effondrements de terrain, soit en évacuant les zones de travail avant qu'un effondrement ne se produise. Les systèmes de surveillance par l'écoute d'émissions acoustiques ne sont qu'un des outils pouvant être utilisés par les ingénieurs de la mécanique des roches; la division de la technologie minière du Centre de recherches Noranda a fait une évaluation des nouveaux instruments connus sous le nom de moniteurs de contraintes "Stress Alert" (RSM). La présente communication livre les résultats de cette évaluation.

EVALUATION OF THE "STRESS ALERT" ROCK STRESS MONITOR IN NORANDA GROUP MINES

INTRODUCTION

The occurrence of rock falls and rockbursts continues to be a major problem in the mining industry. Recent tragic incidents have again demonstrated the serious safety hazards they pose to mining personnel. In addition to these hazards they also incur large economic losses through interrupted production, damage to equipment and damage to the mine construction in the affected area.

In recognition of this, mining industry has always searched for means to identify unstable areas so that action could be taken to either prevent structural failures by alleviating techniques, or to evacuate an area where an imminent failure could be anticipated. Great advances have been made during the past decade towards achieving this goal, resulting in the recent introduction of minewide multichannel acoustic emission systems, which enables the identification of an unstable area in the mine, and also in the development of instruments that have shown promise in the prediction of imminent catastrophic failures.

One of the most recent entries into the domain of acoustic emission monitoring is the "Stress Alert" Rock Stress Monitor (RSM), a single channel instrument which was shown to be able to predict failures in western USA coal mines (1). The Mining Technology Division of Noranda Research Centre has undertaken to evaluate this instrument with the goal of eventually providing the mines of Noranda Group with the capability of predicting structural failures and other catastrophic events.

So far, tests have been conducted at the mines of Geco Division, Mines Chadbourne, Brunswick Mining and Smelting (BMS-M) and Mines Gaspé. The results of the tests conducted in four hardrock mines have been very disappointing and it is doubtful whether the instrument is suitable as an early warning system in mines of similar rock properties.

However, an evaluation of the device in the mine of Lanigan Division, Potash Corporation of Saskatchewan Mining Ltd., gave good results (2), which indicates that the system could find application in the potash mining industry. Noranda is planning to conduct tests at CCP.

DETAILS

PRECURSORY MICROSEISMIC PHENOMENA

As a rock mass is subjected to stress, small scale displacements occur within the rock mass, which result in the release of seismic and sometimes acoustic energy. The small vibrations are called microseisms. When load redistribution occurs in the rock structure surrounding a mine opening, the rock mass at any given point is subjected to changes in stress and, hence, the release of (microseismic) energy. The measurement of this energy by geophysical instruments makes it possible to determine areas of stress build-up.

Several studies have shown that microseismic activity increases with increasing stress to a point where the load exceeds the intrinsic strength of the rock, leading to its eventual failure. At this point, the generation of microseismic energy decreases or stops entirely, probably due to the closing of microfractures in the rock mass (3). The data suggest that the time interval during which the seismic anomalies occur is proportional to the magnitude of the impending failure. Thus, a precursor time of several hundred microseconds for small laboratory rock specimens, several minutes to several hours for mine failures, and a few days to a few years for earthquakes is stipulated.

In an effort by USBM to develop a microseismic roof fall warning system (4) it was found that microseismic anomalies, such as large-scale increases in microseismic event and energy levels followed by rapid decreases, usually preceded roof falls in coal mines. It was noted also that these anomalies occurred at varying amounts of time before the fall, and appeared to vary directly with the volume of material involved in the fall. Subsequent testing of a warning system prototype provided advance warning for 20 of the 23 ground failures which occurred in coal mines (1). Precursor lead times were in the range of 5 to 92 minutes.

Based on these studies a commerical roof fall warning system was developed and is described in the following section.

ROCK STRESS MONITOR (RSM)

The RSM is manufactured and sold in Canada by McPhar Mine Systems Inc. The instrument employed by the Mining Technology Division in the test program consists of (i) a sensor assembly, (ii) a data processing unit and (iii) a chart recorder. A detailed description follows.

Sensor Assembly

The sensor, a lithium sulphate piezo-electric transducer, is mounted in a cylindrical springloaded housing which is attached to a mounting arm via an articulated joint. The arm is clamped on a rockbolt with the transducer placed under pressure onto a flat competent rockface, using a thin plastic sheet as couplant.

The sensor registers microseismic pulses of a frequency ranging from 35 to 100 kHz, generated in the immediate surrounding of the transducer, and transforms it into analog electrical pulses. The signals are transmitted via a preamplifier and a 10 m shielded cable to the processing unit.

Data Processing Unit

The data processor is contained in a single housing, comprising a signal receiver-conditioner, the logic unit and a rechargeable battery providing power for both the processor and the preamplifier.

Signals arriving from the sensor are conditioned for acceptance in the logic circuit. A manual adjustment is employed for threshold adjustment, so that background noise may be filtered out and only event signals of interest enter the processor. The processor is designed to count the number of 'events' as well as their relative magnitude, and updates the data every 60 seconds. The data can be seen on a digital display located in the processor housing. The processor recognizes signals as precursors of a structural failure when the number of events exceed a level of 10 000 per minute on a scale of 20 000 and/or the energy level exceeds 1000 per minute on an arbitrary scale of 2000. At this point an alarm is given.

Chart Recorder

A two-channel strip chart recorder is used to obtain a hard copy of the event and energy counts. The processing unit is provided with a 2 VDC full scale output which transmits the corresponding voltage via coaxial cables to the recorder.

The instrument supplied by McPhar gave a very unsatisfactory performance and was later replaced by a recording system designed by the Mining Technology Division.

TEST PROGRAM

Geco Mine (5)

In 1982, the system was demonstrated in the mine of Geco Division, Noranda Inc.

The initial test took place on the 650 level in the 6-31 bypass drift, an area which had definite ground movement as indicated by ground control measuring stations, track movement, rockbolt squeeze plates and other visual indications. During the 50 minute monitoring period, ground movement was encountered in the region during, which the RSM alarm was activated on two occasions. However, no roof fall was experienced. The instrument was next installed in the 30-65 east drift at section 70 and 50 near the 34-65.2 block, which was caving on the southwall. During a 20-min monitoring period at this location the RSM indicated unstable conditions with the alarm being activated almost continuously. Two more areas were monitored briefly with negative results, which was consistent with known ground conditions.

In conclusion, the mining personnel pointed out the following disadvantages:

- the high cost of the system;
- the fact that three major parts would have to be carried from one monitoring station to another;
- that at the time of testing insufficient experience had been gathered in the mining community to fully understand the instrument's capabilities and limitations.

Chadbourne Mine (6)

The RSM was tested over a period of approximately one month in February 1983 at the Chadbourne Division Mine, Noranda Inc., a gold mine located in the middle of the town of Noranda, Quebec.

The ore deposit consists of a rhyolite-breccia pipe about 100 m in diam which has a vertical continuity of approximately 170 metres. The main orebody is mined by the Vertical Crater Retreat (VCR) method, allowing greater stope intervals and large-hole drilling and blasting operation. The mine has ten levels which extend to about 110 m depth and is accessed by a 3.6 x 5.1 m decline. During the time of testing, mining operations were ongoing on the No. 6 level.

The instrument was installed on a pillar on the No. 5 level near the north raise (Fig. 6.1). This location was chosen for its close proximity to mining activity and the pillar's role as support for a large area of roof, which made it susceptible to stress concentrations. It was hoped that the instrument could be tested for its sensitivity to drilling and blasting in the back of No. 6 level, and to give indication of ground movement or failures. The strip chart recorder, as supplied by McPhar, was found to be unsuitable for around-the-clock long term monitoring, since its battery needed to be recharged every eight hours. To get around this problem, the recorder was installed on surface and was connected to the RSM with two 200-m coaxial cables. During a 15-day monitoring period at this location the mine experienced only one major event on the No. 5 level, which involved a 3500-t piece of rock coming loose from the back. No other events such as ground movement, rockbursts or rock falls were noticed by mining personnel. The time of the major event was not known, except that it happened during a span of three days. During this period the instrument registered microseismic activity for a duration of about two hours which could very well have been the precursor of the event (Fig. 6.2). Normally, the stress and event counts remained at their usual background levels regardless of mining activity, with the exception of Sunday when the mine was idle. During these periods the instrument registered very high activity which could not be explained. An investigation later revealed that during that time electromagnetic interference was transmitted from surface through the recorder cables to the instrument, generating erroneous data.

In summary, the test at Chadbourne was inconclusive. The only major event may have been registered by the RSM; however, this could not be verified due to the lack of data. Although the instrument did not appear to be sensitive to drilling and blasting, it produced erroneous readings on account of electromagnetic interference.

Brunswick No. 12 Mine (7)

After the replacement of the McPhar chart recorder by a suitable underground-service instrument, tests were conducted at the No. 12 mine of Brunswick Mining and Smelting Limited (BMS-M).

The mine produces zinc-lead-copper ore at a daily rate of 10 000 metric tonnes. Operations at the BMS-M No. 12 mine are centered on two major stratiform orebodies. Near the surface the two zones occur side by side, trend north, dip steeply west, and converge at depths to widths of 90 m or more. The ore extends approximately 700 m along strike at the 525-m level and roughly 1300 m at the 850-m level.

Currently, mechanized cut-and-fill (C&F) stoping in blocks up to 137 m high is carried the full width and length of the ore. Inclusions of low-grade material are left in the stopes as permanent pillars. Major stope production originates from the 575-, 725- and 850-m levels. The longitudinal C&F stopes are developed from footwall crosscuts mined at 15-m vertical intervals and interconnected by footwall spiral inclines. Backfill is introduced into the stopes through 1.8 and 3.0-m diam bored raises and is spread by dozers.

A monitoring site was chosen near the 13-16 N stope on the 725-m level. The back of the stope had just been blasted with the ore remaining to be mucked. The drop-zone showed considerable stress redistribution,

resulting in spalling and bursting, which delayed mucking operations by several weeks. The monitoring location at the 15 N sump was within 50 m of the active zone (Fig. 6.3).

Monitoring was begun on June 21, 1983, and continued for 52 days. During this period mining personnel reported any activity in the 13-16 N stope for the purpose of correlating the events with data generated by the RSM. The results are summarized in Table 1.

Table 1 – Summary of data gathered during testing at 725 m No. 2, No. 14, 13-16 N in stope at No. 12 mine, BMS-M

Date	Production data	Unusual behaviour of ground	Microseismic rock monitor data	Remarks
June 25, 1983	Slashing of FW rib and back advance of stope conditioning.	None.	Periodical slight increase in event counts.	
June 26	Ground conditioning.	Minor rock noises inside FW slash.	Event count increase to up to 500 EPM between 15:00-16:00 h. Slight increase in stress count.	
June 28	Ground conditioning.	Minor rock noises.	Periodical slight increase in event counts. Stress: background level.	
June 29	Ground conditioning.	Badly working ground. Numerous heavy ground falls (1-3 t). Snapping and banging originating from FW slash area, propagating towards hanging wall.	Event count increase up to 3000 EPM, starting near midnight, stopping around 21:00 h.	Rock bolters had to abandon the stope.
June 30	Deteriorated stope back conditions necessitated wood cribbing to interrupt stope span.	Minor ground activity in the morning (one hour).	No activity registered.	Observed off-sets in empty cable bolt holes increase in compressive spalling.
July 7	Ground conditioning.	No ground activity registered.	Event count increase up to 3000 EPM, starting at 21:00 h, stopping at 22:00 h. Stress: no data.	Stress recorder out of order.

July 10-13	No work ongoing.	No ground activity registered.	Event count increase up to 2500 EPM throughout the period. Stress: background level.
July 14	Ground conditioning.	Ground was working substantially in the main stope.	No activity registered.
July 18-19	Ground conditioning.	No ground activity registered.	Event count increase up to 2500 EPM throughout the period. Stress: background level.
July 27	Ground conditioning.	Ground was working in the FW pillar drift.	Event count increase up to 300 EPM throughout the period. Stress: background level.
July 28	Blasting in the 15 N crosscut.	Drop cone and crosscut both working slightly.	Event count remained high – up to 300 EPM. Stress: background level.
August 8	No work ongoing.	No ground activity registered.	Event count increase up to 6000 EPM between 1550 and 0230 h. Some increase in stress count.
August 9, 1983	No work ongoing.	No ground activity registered.	Period of high event count (up to 6000 EPM) between 08:00 and 16:00 h. Corresponding slight increase in stress count.

In general, there was poor correlation between observed ground movement and events registered by the rock monitor. The best example would be the event on July 8, when miners had to be pulled out of the area due to "badly working ground", which was not registered at all by the instrument. In other instances, the monitor indicated microseismic activity during periods where no ground movement was observed by workers. One notable exception was a period on June 29 when "badly working ground" coincided with signalling of microseismic activity by the monitor. However, in view of the overall performance it must be assumed that this was coincidental. At no time did the instrument indicate an overstressed condition or sound the alarm, warning of an impending event. Increasing the sensitivity (lowering the TRIG LEVEL) resulted in the increase of

background noise but did not produce an improved sensitivity to the microseisms produced in the working ground. It was also noted that, while the instrument occasionally registered an increased amount of events, it usually indicated zero or only slightly elevated stress levels.

The data suggested that the instrument might have been too distant from the active zone. In order to test for this, the monitor was installed directly in the FW pillar drift, where much of the microseismic activity had taken place (Fig. 6.3). During a three-hour monitoring period good correlation was obtained between audible rock noise and the signalling of microseismic events by the monitor.

Overall, the tests at BMS-M showed that, unless installed in very close proximity to an active area for which the minimum distance could not be established, the RSM does not appear to detect precursory microseismic activity and is not capable of giving an early indication of failure. A sensing range of 100 m radius, as claimed by the manufacturer, is completely unrealistic in view of the results, which makes the instrument unsuitable for mining operations such as BMS-M.

Gaspé Mine (8)

Mines Gaspé is a Division of MacLaren Forest Products Inc., and is located on the Gaspé Peninsula, Quebec, near the town of Murdochville.

Historically, the main copper orebody at Needle Mountain has been exploited by trackless room-and-pillar mining over a stratigraphic thickness of about 150 metres. More recently, deep drilling has disclosed ore occurrences lying as much as 285 m stratigraphically lower than the main orebody, extending from 700 m to 900 m beneath the townsite of Murdochville. This zone, called "E Zone", is in the development stage.

Stress related failures were experienced in this region at the proposed intersection of the M-1 and M-2 conveyor drifts while in the process of developing the M-2 drift. The drift, starting at the access ramp, has been driven approximately 60 metres. Near the face it intersects a 4-5-cm marker bed filled with quartz at an angle of approximately 30.

The failures included violent ejections of rock from the centre of the back near the face, usually following a blast. Large amounts of loose also accumulated in the wire mesh of already conditioned ground. This situation presented a good opportunity to test the RSM in close proximity to a very unstable zone, and tests were conducted over a period of four days, starting April 24, 1984.

The instrument was installed initially in the 2901 W drift near the face. At this location, the sensor was approximately within 30 m of the M-2 drift, and it was assumed that microseismic activity in the unstable region would radiate beyond the sensor location (Fig. 6.4).

Monitoring was begun at 15:00 h on April 24 and continued until next morning. No sign of microseismic activity was registered by the instrument during this period, although mining personnel reported rockbursting activity in the M-2 drift. This result was consistent with earlier experience with regard to limitations in distance.

The instrument was subsequently installed in the M-2 conveyor drift, approximately 12 m from the face. A location for the sensor was chosen on the wall, approximately 4.5 m off the floor (Fig. 6.4). Work was in progress to condition the back with rockbolts, rebars and wire mesh.

Monitoring was begun at 10:00 h on April 25. The instrument was pulled out after 23:00 h of monitoring. The following observations were made during this period:

- Scaling, drilling and rock bolting resulted in a sharp increase in recording of event and stress levels, setting off the alarm several times. The TRIG LEVEL (TL) was adjusted from 0.18 (normal setting for background noise filtering at this location) to 0.35 to prevent triggering the alarm.
- During lunch break, the instrument did not respond to cracking and popping in the back, although the TL was readjusted to 0.18.
- The instrument registered high values again as soon as work commenced in the afternoon.
- During the remainder of the monitoring period, the high-low signal pattern repeated itself and correlated well with ongoing mining activity (Fig. 6.5).

It was evident from these observations that although the instrument responded to mining activity, it did not register microseisms generated during stress redistribution. The apparatus was removed from the site temporarily so that preparations could be made for blasting, which was scheduled for 06:00 h on April 27.

Testing was resumed on April 27, approximately two hours after blasting. The instrument was installed as previously, verifying that the sensor was accurately placed in the same location as in Test No. 1. At the time of installation, there was no apparent microseismic activity, which allowed the TL to be set to the normal background level of 0.18, with the proviso that it could be readjusted in the event of increased microseism. Monitoring was begun at 08:27 h and continued through to 07:45 h of April 28 for a total of approximately 23 hours. During the initial hours of monitoring, the site was closely observed in order to correlate events with signals generated by the instrument. The following results were obtained from the test:

- During the period observed, starting at 08:27 h and ending at 12:31 h, activity took place in the drift near the blasting zone. A total of 12 rockbursts were observed, of which one burst dislodged a one-tonne piece of rock containing two sheared-off rebars. Considerable stress concentration must have been involved in the latter event, which took place within 4.5 m of the sensor. In addition to the rockbursts, cracking and popping could be heard throughout the observed period.
- All the microseismic activity taking place within a few metres of the sensor was not registered by the instrument. Readjustment of the threshold setting to increase the sensitivity only resulted in a slightly elevated background signal level but gave no indication of the ongoing observed events.
- The RSM gave similar negative results for the remainder of the monitoring period.

The tests at Mines Gaspé provided an excellent opportunity to simultaneously observe violent failures of unstable ground and monitor the events at very close proximity with the McPhar Rock Stress Monitor.

Although the instrument registered mining activity such as scaling, drilling and rockbolting very well, it did not respond to microseismic activity, the precursors of the rockbursts, and other events observed in the M-2 drift following a blast round. Malfunction of the device was ruled out on account of tests subsequently conducted in the laboratory, and it was concluded that the instrument was incapable of registering microseismic events which must have been of a considerable magnitude during the observed period.

DISCUSSION

Although the instrument did register the occasional microseismic event during some of the field tests, it did not reliably indicate precursors of imminent structural failures or rockbursts. As such, the instrument is unsuitable as an early warning system in most of the Noranda Group mines, which are typical hardrock mines. The results are consistent with those obtained by CANMET during tests in three hardrock mines in Northern Ontario (9).

It is difficult to explain the poor performance of the device, especially in light of its apparent success in coal and potash mines. Research has shown that the higher frequency components of a rock-noise waveform are rapidly attenuated with increasing travel time (10). The results are therefore surprising since it should be expected that travel times in hardrock are shorter than those in softrock, on account of its higher travel velocities, and that the instrument's high frequency sensor (35-100 kHz) should have fewer difficulties in registering these microseismic signals.

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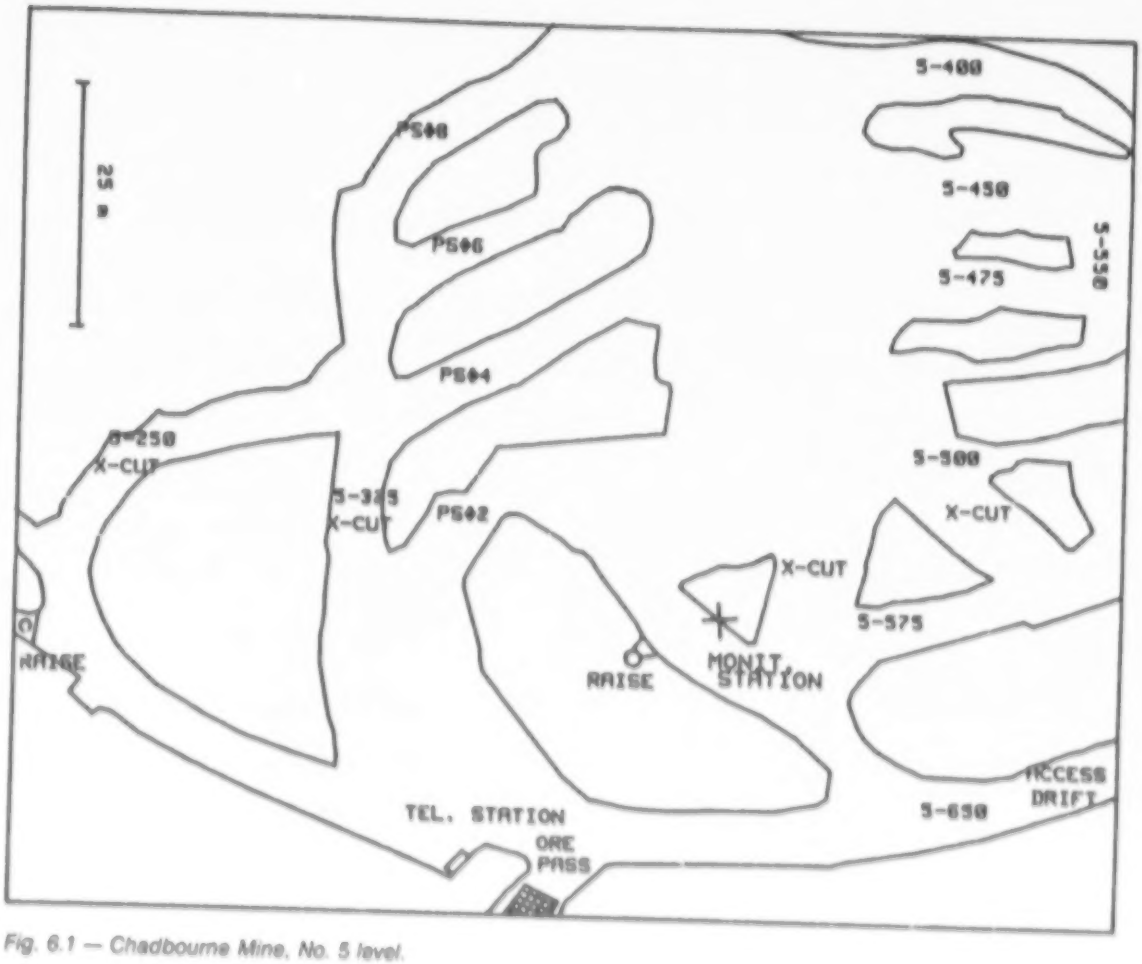

Fig. 6.1 — Chadbourne Mine, No. 5 level.

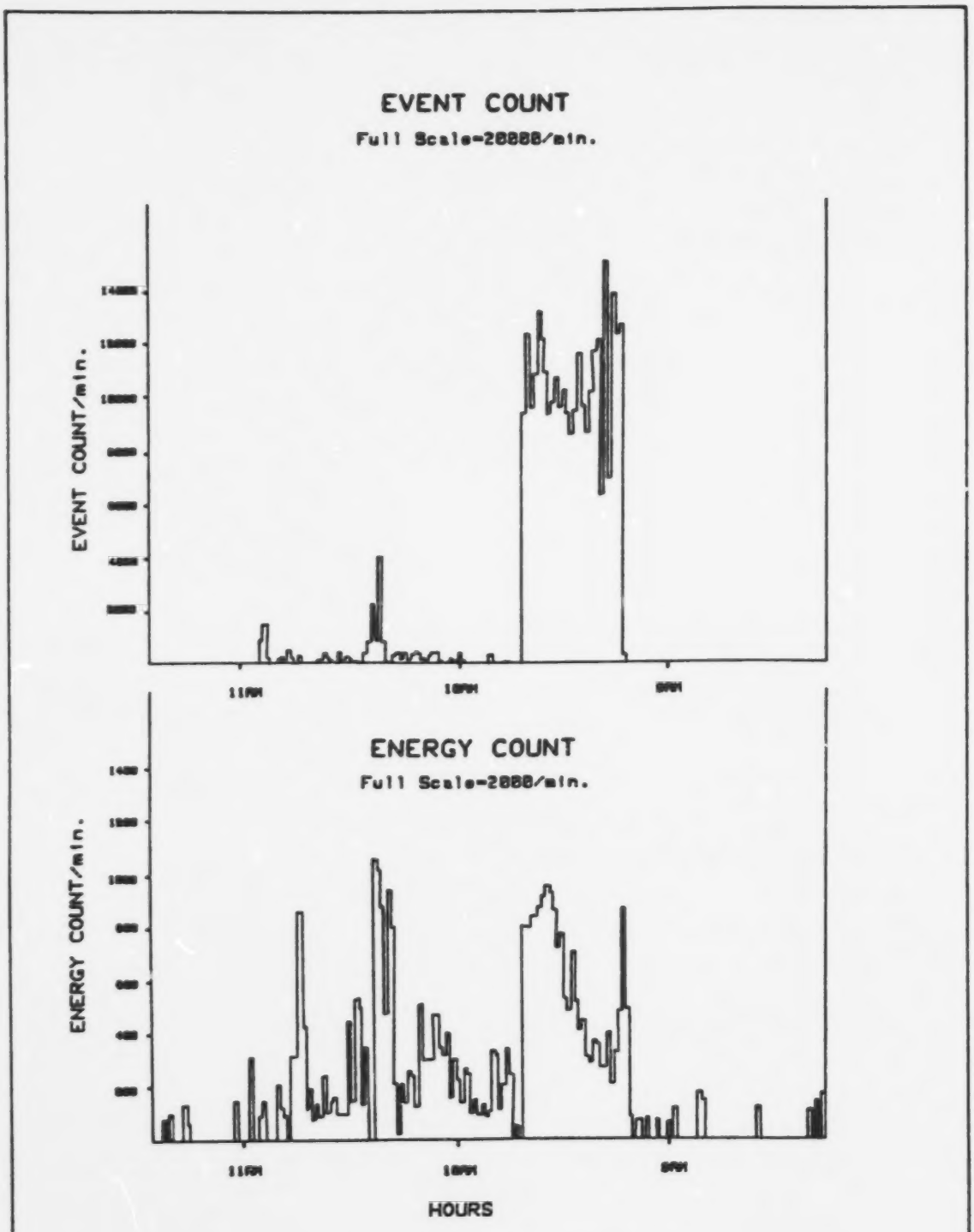

FIGURE 2

MICROSEISMIC ACTIVITY REGISTERED WITH THE ROCK STRESS MONITOR ON FEBRUARY 9, 1983
IN THE CHADBOURNE MINE, NORANDA, Québec

Fig. 6.2 — Microseismic activity registered with the Rock Stress monitor on February 9, 1983, in the Chadbourne Mine, Noranda, Quebec

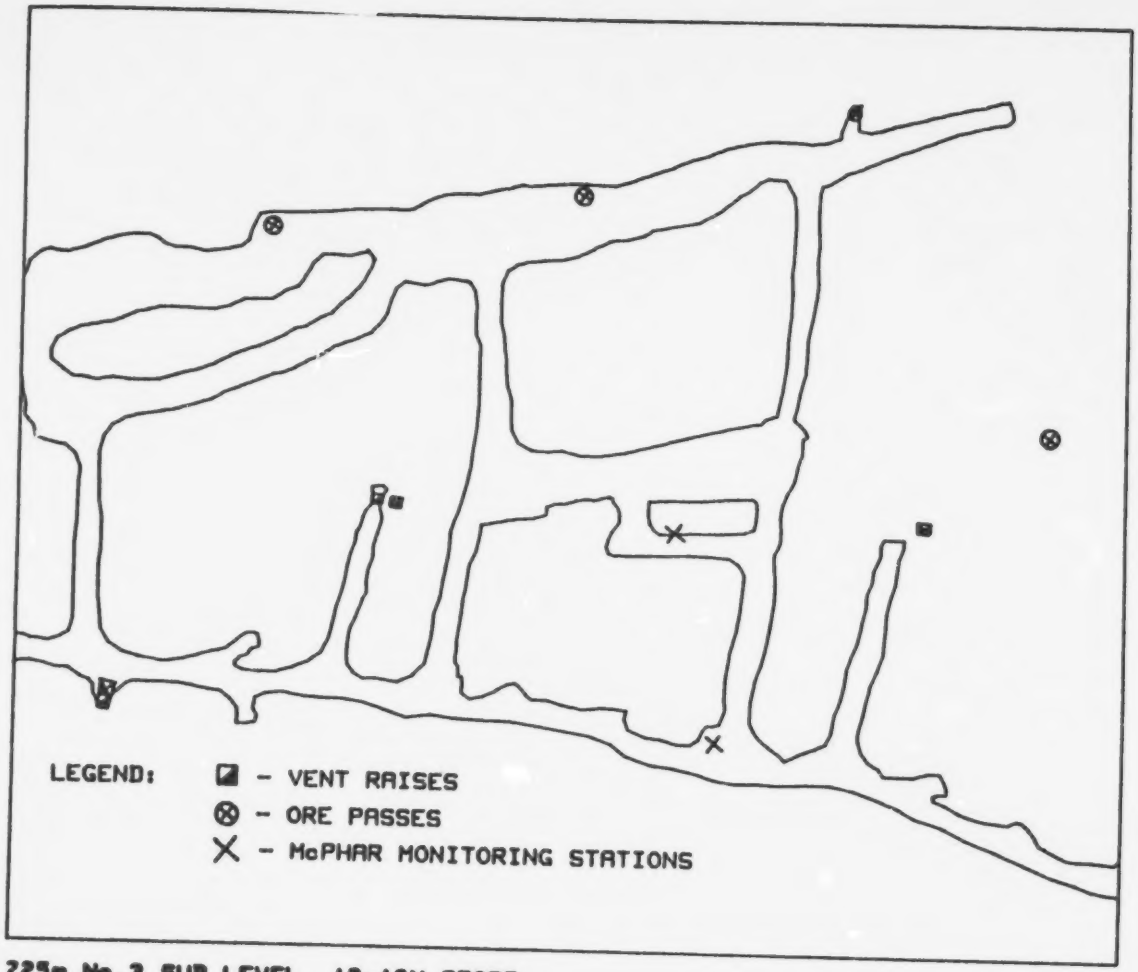

Fig. 6.3 — Brunswick Mining No. 12 mine monitoring stations on the 725 m No. 3 sub-level

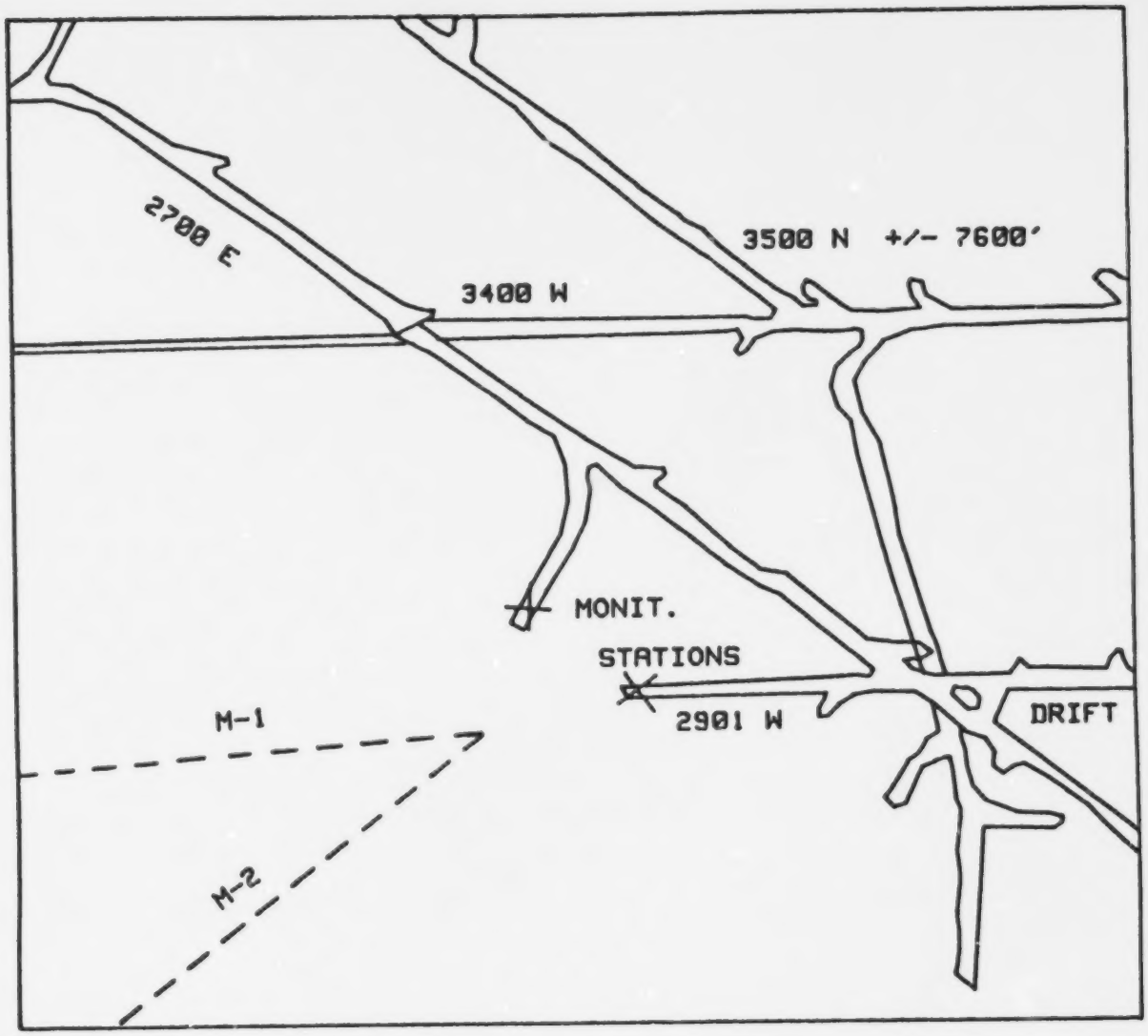

Fig. 6.4 — Mines Gaspé monitoring stations in the "E" zone

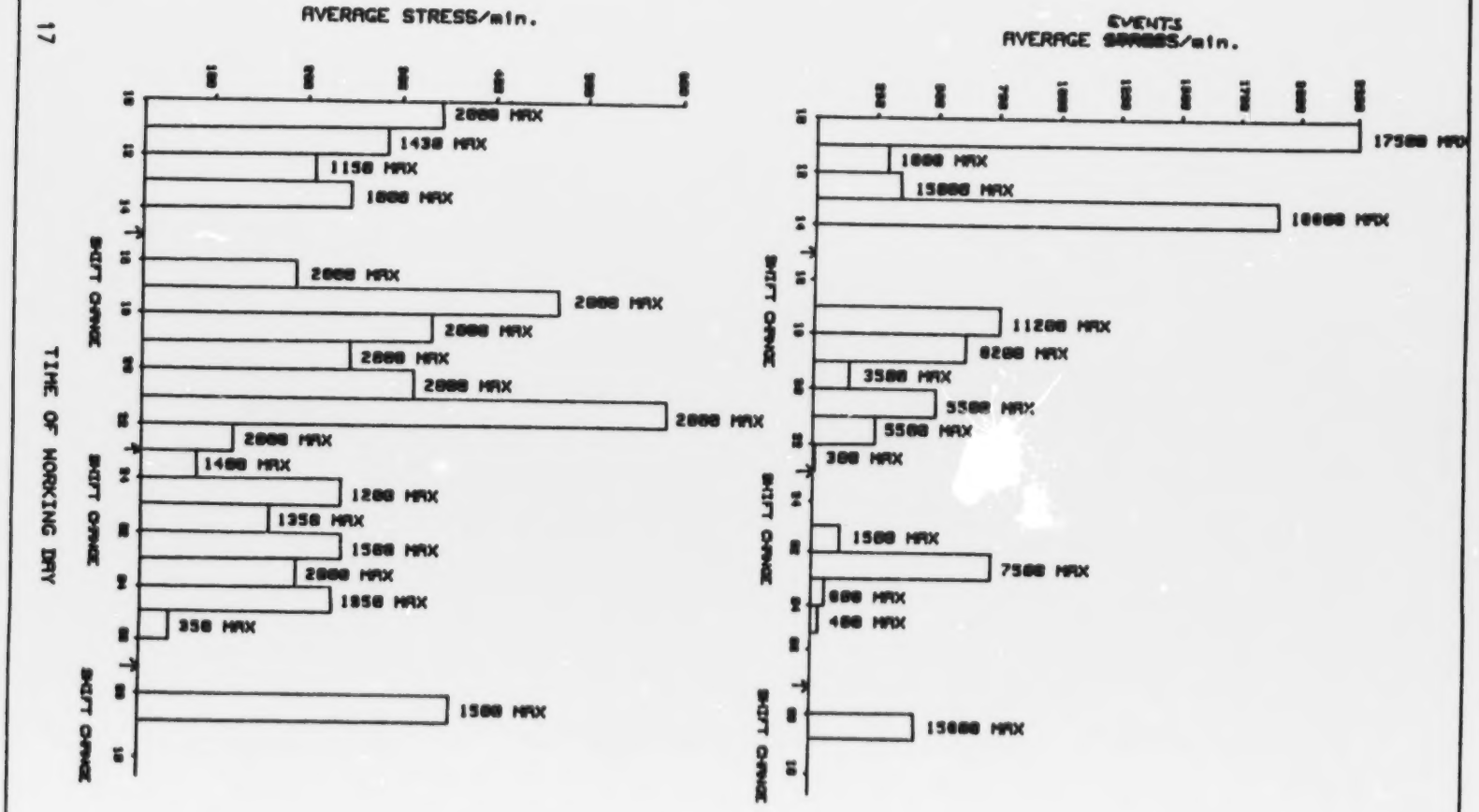

FIGURE 5

MONITORING IN THE M-2 DRIFT ON APRIL 25-26, 1984

Fig. 6.5 — Monitoring in the M-2 drift on April 25-26, 1984

HIGH FREQUENCY MICROSEISMIC MONITORING AT PCS MINING

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ABSTRACT

PCS Mining has been actively conducting field trials and laboratory experimentation in high frequency microseismic monitoring. Using equipment under the trade name "Rock Monitor", in situ testing has shown the capability of obtaining data related to stress redistribution due to mining.

Laboratory testing confirmed a good correlation between the number of microseismic events and applied load for potash samples. Underground experiments further showed a good correlation between microseismic events and both load and closure.

Work in progress is designed to provide a better understanding of the quantitative relationships between microseismic events and applied load, and in underground studies to observe stress redistribution using a multichannel monitoring system.

SURVEILLANCE MICROSISMIQUE HAUTES FRÉQUENCES À LA PCS MINING

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RÉSUMÉ

La PCS Mining a effectué de nombreux essais sur le terrain et de nombreuses expériences en laboratoire sur la surveillance microsismique hautes fréquences. Des essais in situ menés à l'aide de l'équipement connu sous le nom de commerce de "Rock Monitor" ont révélé qu'il est possible d'obtenir des données sur la redistribution des contraintes résultant de l'exploitation.

Les expériences en laboratoire ont confirmé qu'il existe une bonne corrélation entre le nombre des événements microsismiques et la charge appliquée aux échantillons de potasse. Des expériences dans le sous-sol ont en outre révélé une bonne corrélation entre des événements microsismiques d'une part et la charge et la fermeture de l'autre.

Les travaux en cours sont conçus de façon à fournir une meilleure compréhension des relations quantitatives entre les événements microsismiques et la charge appliquée et, dans des études souterraines, à permettre d'observer la redistribution des contraintes par le recours à un système de surveillance à plusieurs voies.

HIGH FREQUENCY MICROSEISMIC MONITORING AT PCS MINING

INTRODUCTION

PCS Mining, Cory Division, is located in south central Saskatchewan, approximately 7 km northwest of the city of Saskatoon (Fig. 7.1).

Figure 7.2 illustrates a composite stratigraphic section of the general geology at PCS Mining, Cory Division. Near Saskatoon, the phanerozoic sedimentary sequence attains a thickness of approximately 1700 metres. The sequence consists of about 600 m of sands and shales overlying a carbonate-evaporite series. The carbonate-evaporite sequence is about 800 m in thickness.

PCS Mining, Cory Division extracts ore predominantly from the "A" zone of the Patience Lake member of the Prairie Evaporite, more than 1000 m below surface. The Prairie Evaporite is composed mainly of alternating beds of halite and sylvite having an average total thickness at Cory Division of approximately 200 metres. The mining horizon is situated near the top of the formation. The Prairie Evaporite formation is overlaid by thick sections of fairly strong, dense and non-porous paleozoic carbonate rocks.

The potash mining height in the "A" zone is approximately 3.4 metres. The mining system is highly automated utilizing continuous borers and extensive conveyor haulage.

The current mining method employs the time-controlled stress relief technique and allows efficient mining of the "A" zone potash horizon with minimal use of conventional ground support system. Below the "A" zone are several other potash beds with the "B" zone presently being investigated for its mining potential.

UNDERGROUND MICROSEISMIC TEST PROGRAM

During the month of April, 1982, PCS Mining, Cory Division, in conjunction with PCS Mining Research and Development, embarked upon an underground study utilizing a high frequency microseismic instrument, the RM1 Rock Monitor. The main objective of the study was to observe high frequency microseismic behaviour in an evaporite ore horizon with particular interest in outlining the potential for ground fall detection.

Figure 7.3 illustrates the location of the microseismic test site with respect to the overall mine layout. The site location was established near the advancing mining face and in the centre entry of a mining panel.

The initial study indicated that the high frequency microseismic event count changed in response to mining activity with the implication that the microseismic activity was related to mining through the process of stress redistribution.

Due to the favourable result of the initial study, it was decided to conduct further investigations to more clearly understand and quantify the relationships.

Figure 7.4 shows typical results for the rock monitor situated approximately 70 m from the mining face.

Recent underground testing has shown that a good correlation exists between load redistribution, closure and high frequency microseismic event (Mottahed and Vance, 1984).

Figure 7.5 shows the type of correlation obtained in underground experiments at PCS Mining Lanigan Division.

LABORATORY INVESTIGATIONS

Laboratory investigations using facilities at the University of Saskatchewan, were conducted in the summers of 1982 and 1984.

The work to date has indicated the following:

1. A good correlation exists between applied load and high frequency event count.
2. A good correlation exists between strain and high frequency event count.
3. The Kaiser effect was exhibited by potash ore.
4. The waveform of the events was comparable to the waveforms reported within coal mines.
5. Precursor warnings were given prior to failure of some of the specimens.

Correlation Between Load and Events

It was previously reported (Vance, 1983) that a correlation was observed between applied and cumulative event counts. Figure 7.6 shows a typical graph of the number of events as a specimen was incrementally loaded.

The procedure used for the sample of Fig. 7.6 was to load the sample in successive increments, maintain a steady state load at each increment and record the events per minute until the number of events decreased to a predetermined level. This predetermined level was defined by the internal 'noise' of the rock monitor instrumentation.

Figure 7.7 illustrates the number of events with time through several loading cycles for the ore specimen. Generally, the final load for each increment was reached at a time coincident with the highest event value. Thus, events following the peak represent the time the sample was maintained at constant load. Subsequent experiments incorporating strain measurements verify that this continued event activity at constant load is related to 'creep' of the potash ore.

Correlation Between Strain and Events

As a result of the underground testing program it became apparent that a correlation existed between the rate of entry closure and the microseismic event count. In order to further evaluate the above correlation, strain measurements were incorporated into subsequent lab testing. Figure 7.8 illustrates the cumulative number of events and total sample compression versus load for the initial loading of a potash sample.

Similarly, Fig. 7.9 compares the number of events versus the incremental strain for the identical potash sample, per one minute interval.

Kaiser Effect

The testwork to date has shown that the Kaiser effect was in fact present in potash ore. Figure 7.10 shows results for a sample which was subjected to two periods of loading to test for the Kaiser effect. The plot indicates that upon reloading, significant event counts were not obtained until the original load level was exceeded.

Waveform of Microseismic Events

In recent laboratory tests, an oscilloscope was operated to observe the waveform of the output from the rock monitor transducer. Discrete events with amplitudes considerably above background were observed. The waveforms bore marked similarity to those noted by Fisher (1980) and described as "near failure pulse data". Figure 7.11 illustrates the waveform reported by Fisher.

Recent experiments, done by PCS Mining, show similar waveforms from potash specimens (Fig. 7.12).

In order to record the waveforms of successive events occurring over the time interval, a longer sampling period (a lower sampling rate per unit time) was utilized. This resulted in the compression of the waveform on the display, as shown in Fig. 7.13. Thus, it was found that events typically showed the common horn shape of lower frequency seismic events.

CONCLUSIONS

The work completed to date at PCS Mining has shown potentially useful correlations between high frequency microseismic events and several rock mechanics properties in potash. The ultimate test of the value of this information will be their application to practical mining situations. The current research activities at PCS Mining, Cory Division, includes the operation of a 6-channel RM6 Rock Monitor, in conjunction with an Electrolab 250 microseismic source location system.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of the following individuals from PCS Mining; Parviz Mottahed, Divisional Engineer, Aldean Amy, R & D Mining, who collaborated in the recent laboratory testing; Thelma Potter, R & D Mining, for preparation of the manuscript, and the Management Committee of PCS Mining for permission to present this paper.

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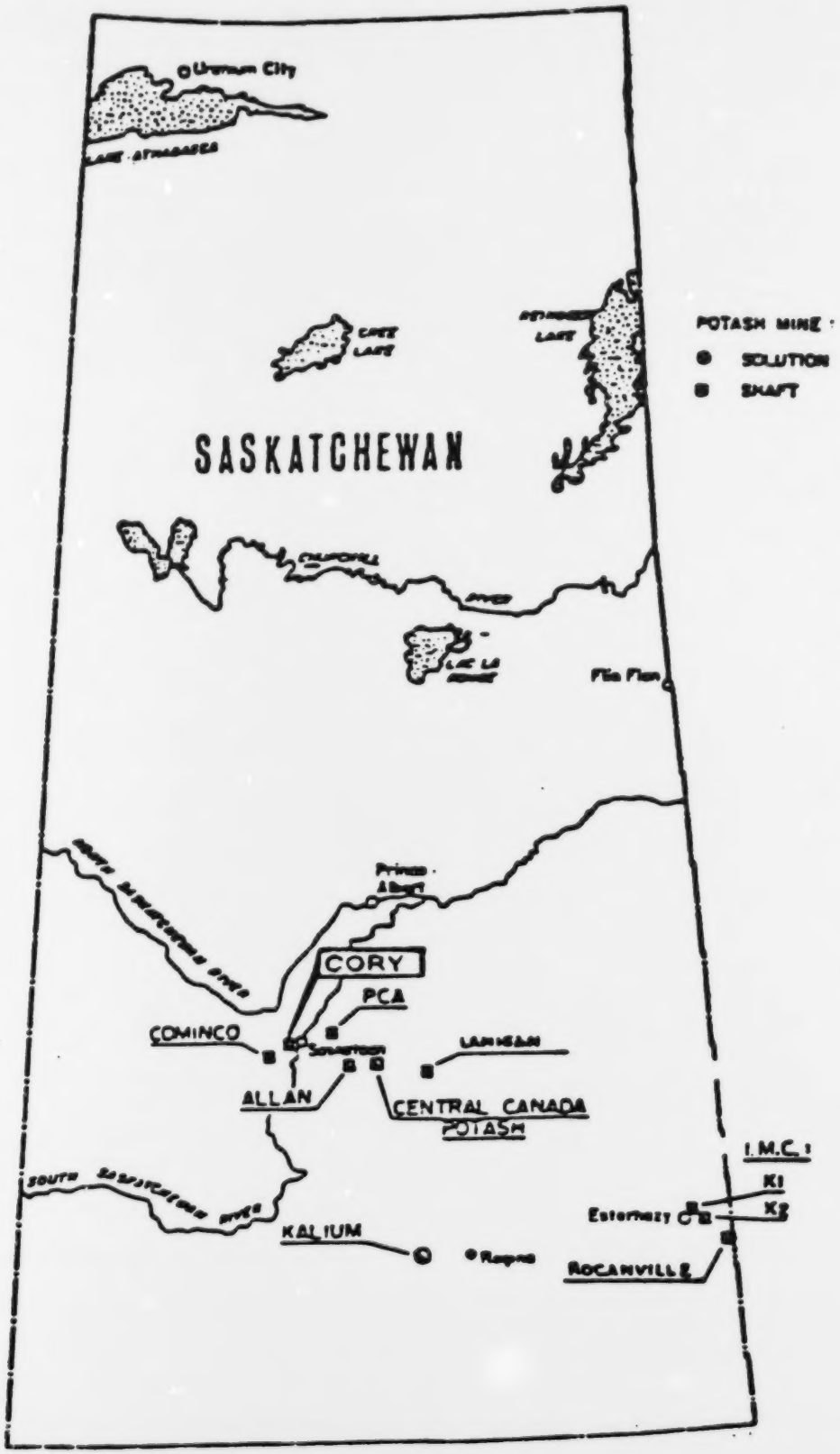

Fig. 7.1 — Location of potash mines in Saskatchewan

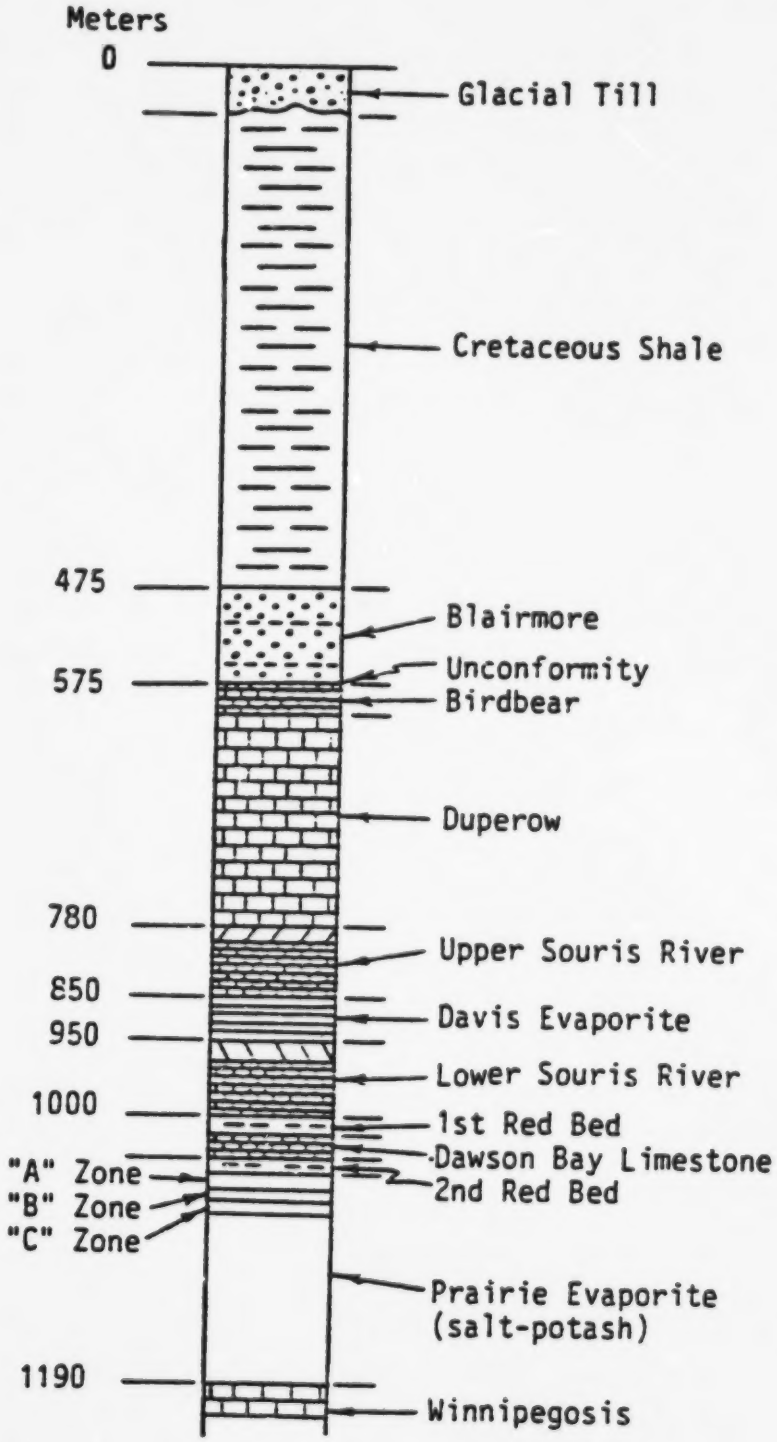

Fig. 7.2 — Composite stratigraphic section general geology

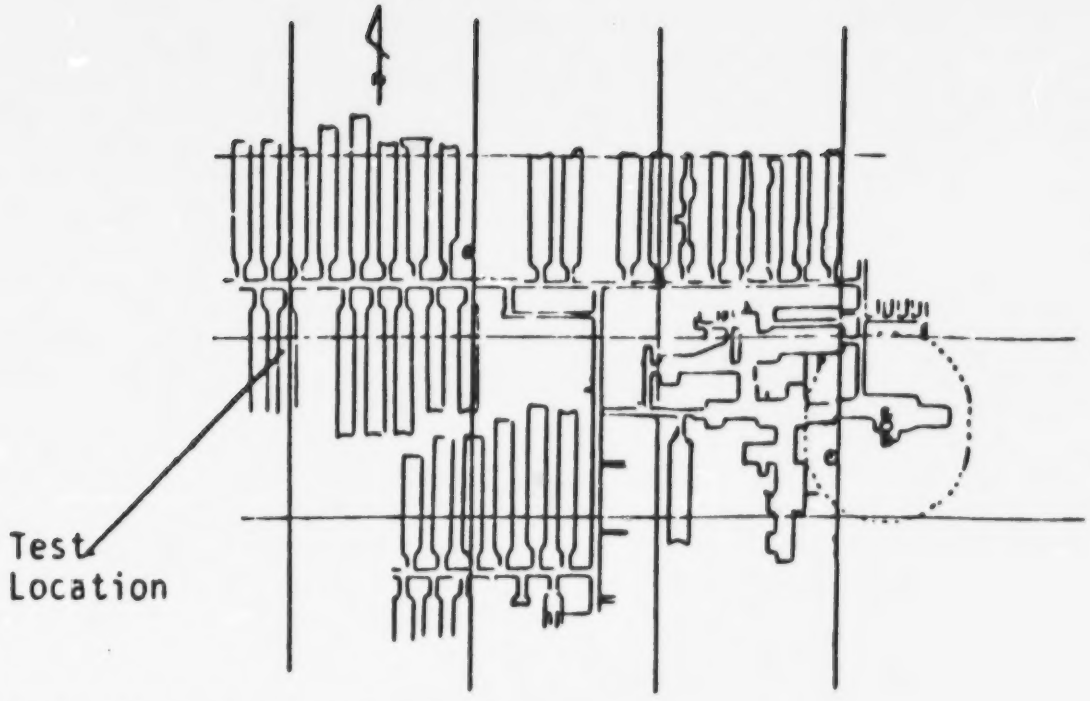

Fig. 7.3 — Mine location plan microseismic test site

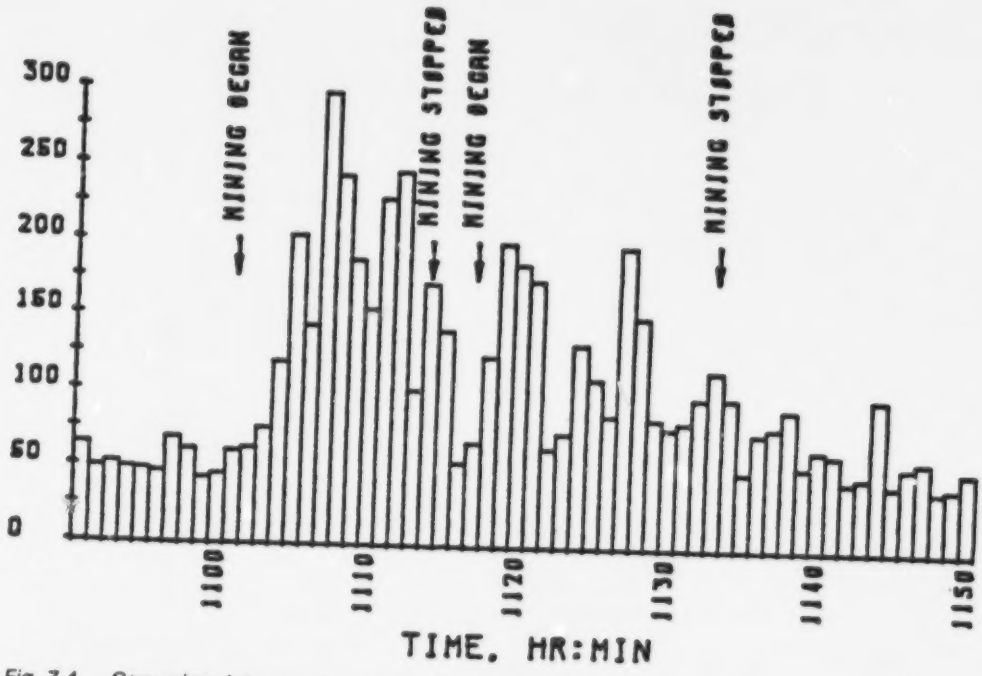

Fig. 7.4 — Cory mine data, events vs. time (after Vance, 1983)

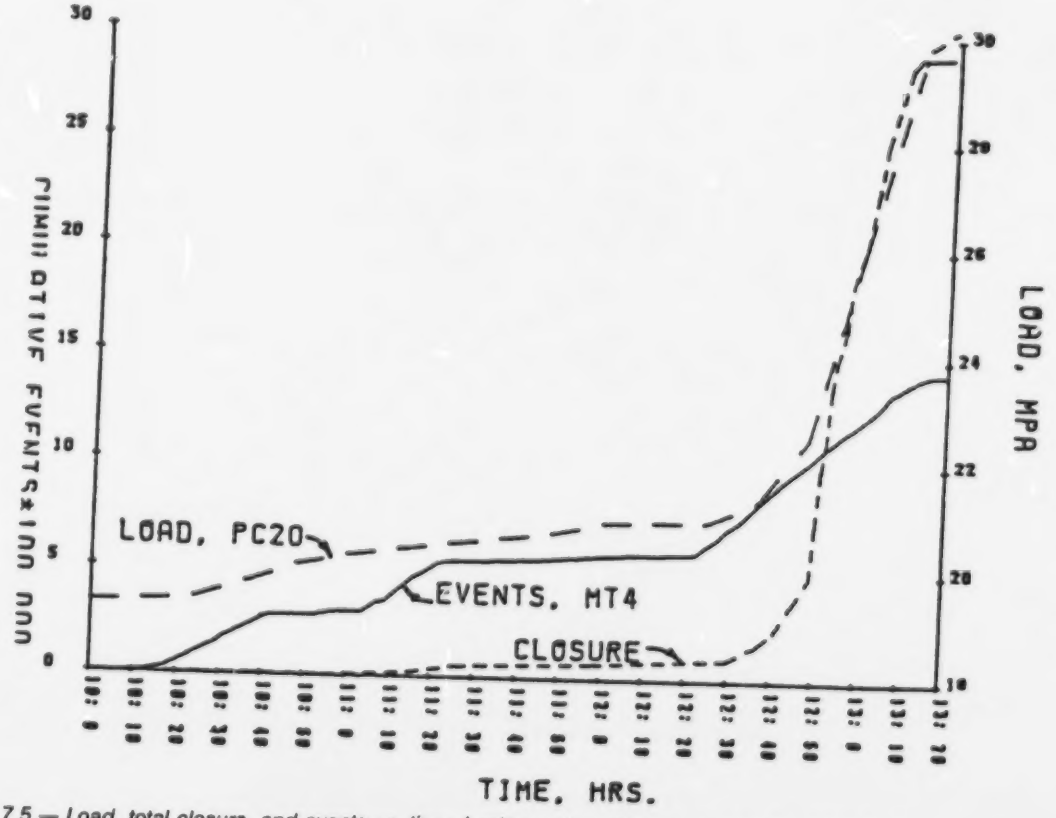

Fig. 7.5 — Load, total closure, and events vs. time, Lanigan mine, Feb. 13, 1984 (after Mottahed and Vance, 1984)

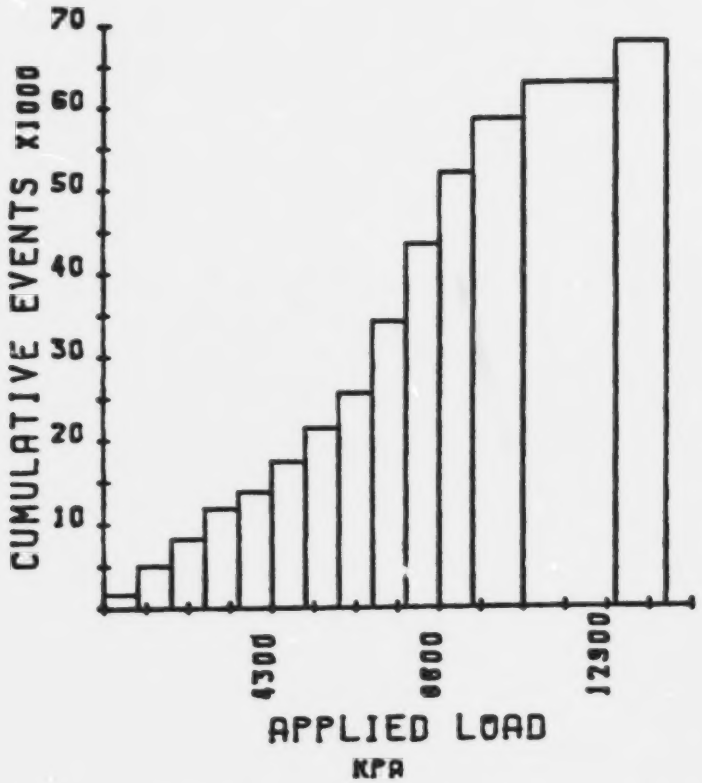

Fig. 7.6 — Cumulative events vs. applied load (after Vance, 1983)

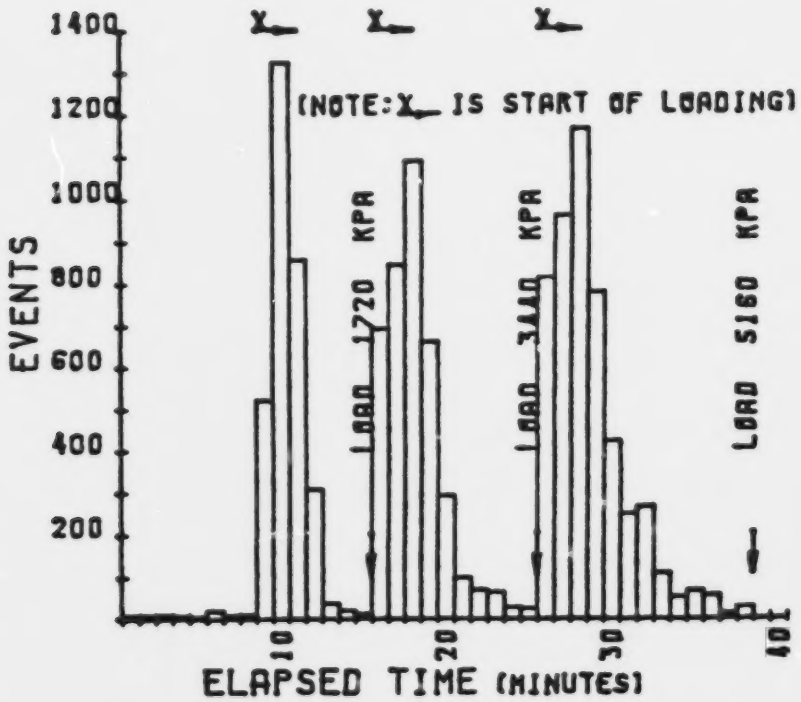

Fig. 7.7 — Events vs. time (after Vance, 1983)

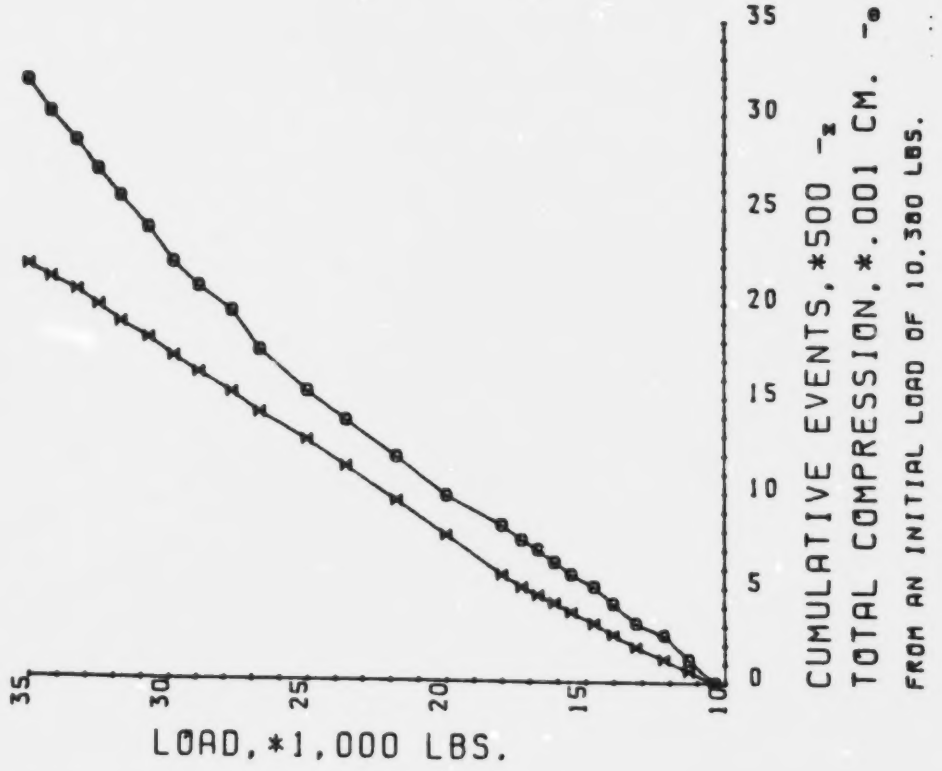

Fig. 7.8 — Cumulative events and total sample compression vs. load

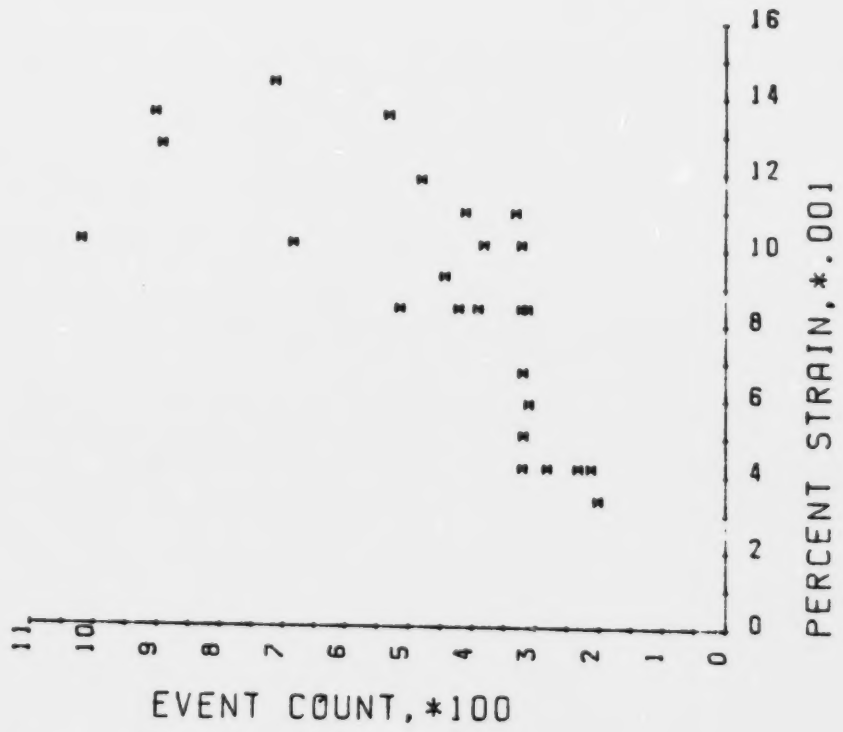

Fig. 7.9 — Events vs. incremental strain per one minute interval

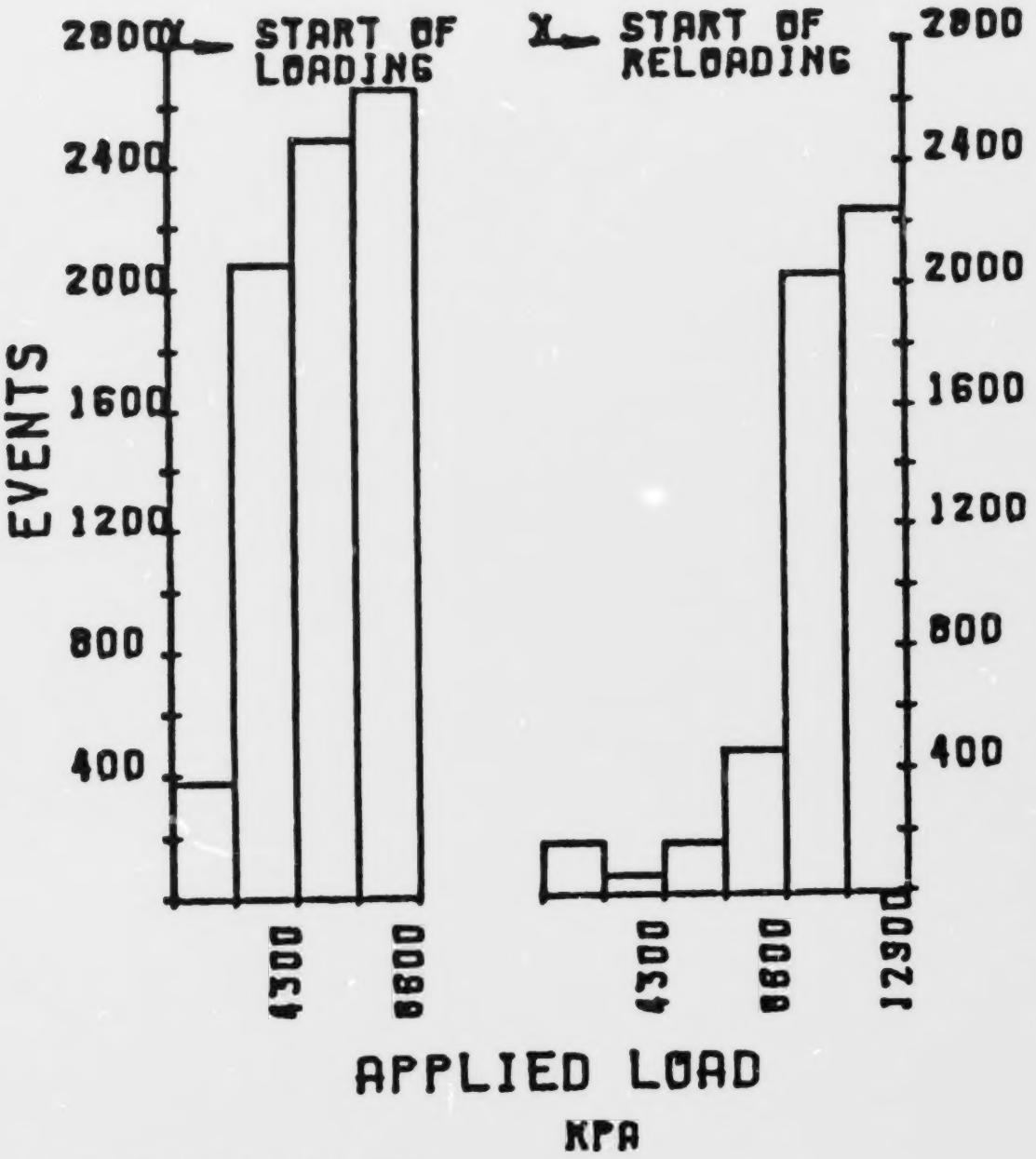

Fig. 7.10 — Kaiser effect (after Vance, 1983)

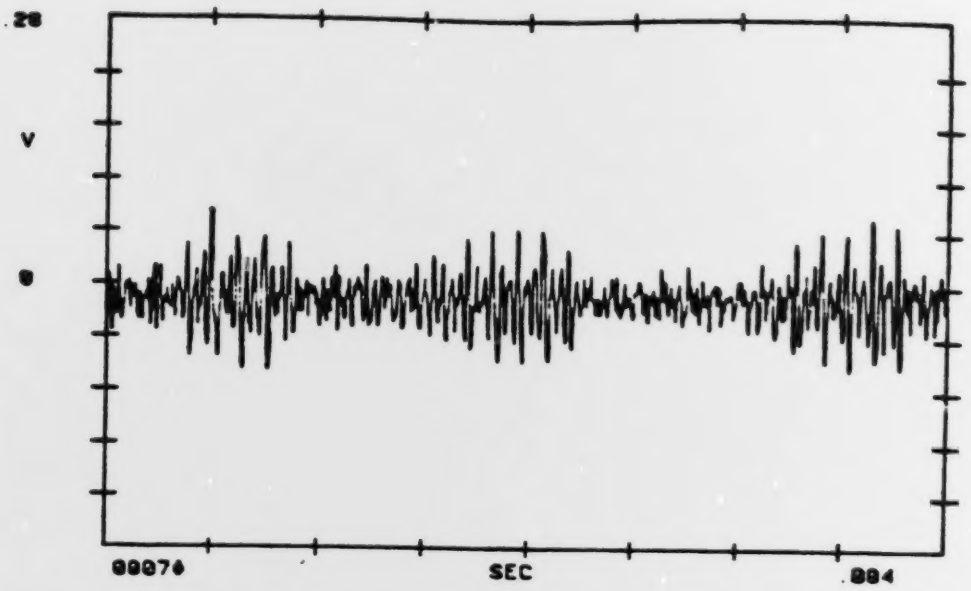

Fig. 7.11 — Near failure event data (after Fisher, 1980)

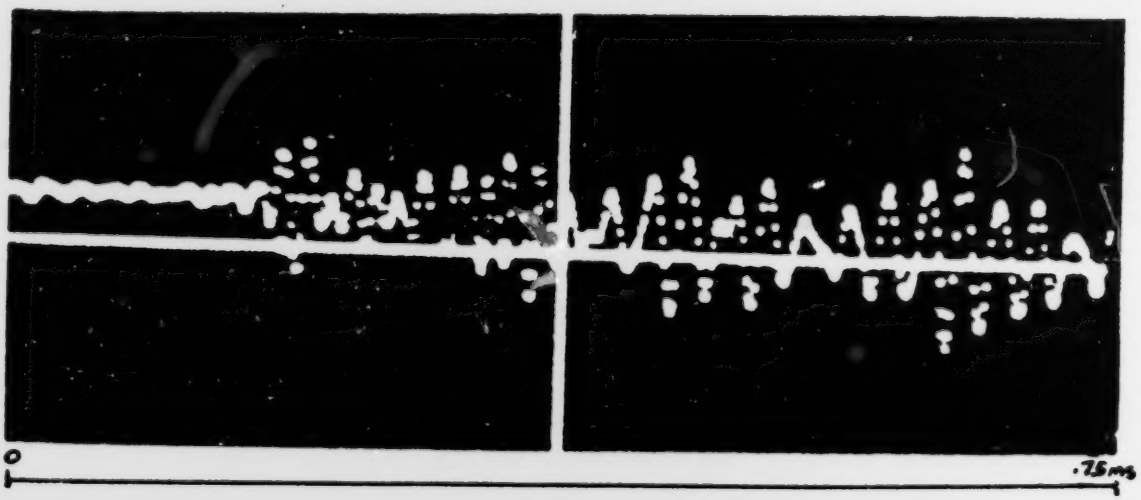

Fig. 7.12 — Typical event waveform – potash specimen

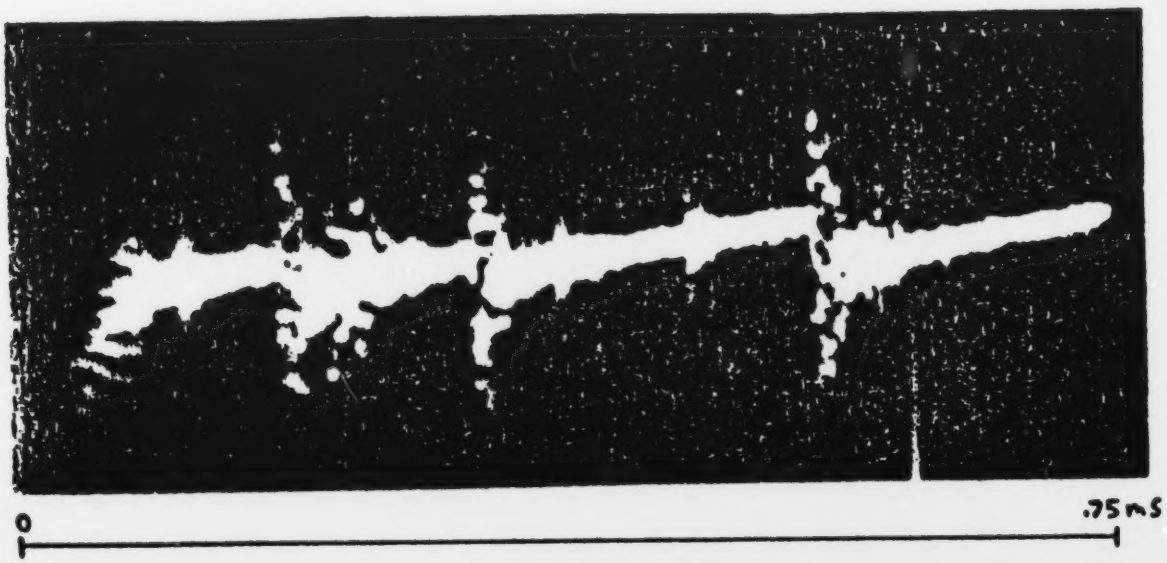

Fig. 7.13 — Successive events

DISCUSSION

A general discussion was conducted on the application of high frequency microseismic monitors to underground stability problems.

T. Vladut: Do you have a feeling for the size of roof falls that can be predicted and the length of time of the warning?

J. Vance: We have insufficient data for potash mines, but the distance between the detector and the roof fall at Cominco was 250 ft, and the effects of mining were detected up to 1400 ft away at Lanigan mine. These signals are not being transmitted 1400 ft, not even 14 ft, but we are measuring local responses to changes in the overall conditions.

H. Miller: Unlike other mines, espcially hardrock mines, it is possible to detect the effects of mining, e.g., convergence at great distances, perhaps over 1000 feet.

In addition, work in South Africa showed that vibrations with frequencies above 35 kHz could not be detected in quartzite at any distance greater than 20-30 ft from the source. It must, therefore, be redistributed stresses that cause these events in potash.

P. Cain: In Cape Breton, a small peak in activity was noted prior to a very small (6" x 4") piece of rock falling from the roof to the drift. Alarms were regularly caused by opening a ventilation door. However, at very close proximity to a roof bolter and a coal cutting machine, no activity was recorded, even with low thresholds.

B. Welsh: We have also had peaks in activity associated with the use of compressed air close to the instrument.

J. Vance: Contrary to other people's experience, we have had no false alarms or instrument failures. Whether or not there have been changes in hardware, I don't know, and the records from the potash mines are completely different from those in hardrock mines. It might be worthwhile to use two instruments at the same location.

P. MacDonald: There may not be any difference in the instruments, but rather there is a contrast in microseismic activity in hard, compared with soft rocks.

J. St. Pierre: When the Falconbridge instrumentation group examined the high frequency monitor, it was rejected as it was detecting a skin effect, where waves were propagated on the surface of the excavation. This doesn't make the measurements invalid, however, it doesn't seem representative of much, and the instrument would have to be very close to anything that occurred. Fourier analysis of blast vibrations suggested that about 20 ft was the limit of detection of frequencies greater than 5 kHz, thus 35 kHz seemed unreasonable.

P. MacDonald: It is apparent that rather than picking up the source events themselves, the rock monitors detect small events induced by stress redistribution. Without more research on the subject, it's very difficult to understand the nature of these induced events. From the results presented so far, it seems that induced events are not detected in hardrock mines. Peaks in activity often appear to be due to gross vibration of the instrument itself rather than stress redistribution. The general range of detection, where any effects have been seen, appears to be around 50 ft from the source event. This indicates that there are different mechanisms in hard and soft-rock mines.

C. Page: One thing that is apparent is that the instrument seems to have worked in room and pillar mines. In what configurations was it used in the potash mines?

J. Vance: We found best results were obtained when we were monitoring adjacent to a competent pillar.

C. Page: Perhaps the instrument would work where significant closure was taking place, for instance in the open stopes at Denison, rather than in the other types of mines.

B. Welsh: It's possible that we don't have the continuity in the rock mass that is found in other mines.

J. Bourbonnais: Placing the detector at the end of a 5 or 6 ft borehole may increase the possibility that competent and continuous rock is being monitored in hardrock mines, and the results may then be more similar to those at PCS.

J. Vance: When installed in a borehole, the results were similar to a surface mounted transducer. However, the number of events were an order of magnitude less for the in-hole detector. The likely reason is that microscopic yield, that produces events, takes place over a much greater area on the free surface than in the borehole.

C. Malott: Some of the instrument anomalies are explainable. Movement of the transducer cable resulting in a peak in activity is due to the triboelectric effect and is caused by the use of inappropriate cable with the very low signals. In USBM tests, it was found that completely coincidental arrivals were recorded on several channels using detectors of this type. This is consistent with cross-talk between the channels. It is also possible that ground currents could be detected by these systems, resulting in anomalous readings. This may explain how effects are detected at distances over 1000 ft from the source event. The source would need to be of many megajoules to transmit high frequencies over such large distances and these don't seem to have taken place.

H. Miller: In South Africa, areas considered prone to rockbursts were instrumented with orthogonal accelerometers with broadband frequency response changing patterns in activity being recorded, however, these patterns were variable prior to rockbursts. We ended up with a lot of data with no set patterns. It seems worth looking at the source mechanisms of these events allied to the mine stress distribution. Research is currently being conducted at UBC into the relationship between the mine loading system and the mechanisms of microseismic events.

C. Page: In South Africa, use is made of the Energy Release Rate. Whether or not this is an accurate assessment of released energy, it has been shown to be related to the incidence of rockbursts.

T. Yu: Tests at Kidd Creek with the Stress Alert indicated that a specific couplant thickness was required. In addition, the transducer required a setting pressure of 500 psi to work efficiently.

H. Kanduth: We found no difference between results with or without a coupling sheet.

P. Oliver: It appears that some of the results that have been presented are not of a seismic nature. Perhaps a different type of detector, e.g., electro-magnetic, should be investigated. Maybe if we knew what we were measuring, we would know why we can detect events in coal and potash, but not in hardrock.

H. Miller: Laboratory tests may give an indication of the differences. Microseismic acitivity is produced by hardrock samples only at loads near their strength. However, potash releases microseismic energy at very low levels of stress. A lot more fundamental research is therefore required.

* * *

MICROSEISMIC MONITORING AND STUDIES AT KIDD CREEK MINES

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ABSTRACT

Several cases of seismic disturbance associated with, or without, an expulsion of rock have occurred in the past at the mines. Microseismic monitoring is therefore used to detect the degree of seismic activity in a questioned area to help evaluate the ground conditions for maintaining a safe working place.

Two types of monitoring devices have been used in the mines for recording relative event rates and seismic amplitudes. The composite recorded data made it possible to interpret the seismic information more objectively.

This paper describes the equipment used and the measured results from underground and laboratory case studies, together with some rock mechanics concepts used at Kidd Creek Mines for preventing the occurrence of rockbursting.

SURVEILLANCE ET ÉTUDES MICROSISMIQUES À LA KIDD CREEK MINES

T.R. Yu
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RÉSUMÉ

Plusieurs cas d'agitation sismique avec ou sans éjection de roches se sont produits dans les mines. Nous avons donc recours à la surveillance microsismique pour déceler la force de l'agitation sismique dans une zone douteuse, ce qui nous aide à évaluer les conditions du sol en vue de maintenir la sécurité des travailleurs.

Deux types de dispositifs de surveillance ont été utilisés dans les mines pour enregistrer la fréquence et l'amplitude des agitations sismiques. Les données enregistrées ont permis une interprétation plus objective des renseignements sismiques.

La présente communication décrit l'équipement utilisé et les résultats obtenus à partir d'études in situ et en laboratoire, ainsi que certains concepts de la mécanique des roches appliqués dans les mines Kidd Creek pour prévenir les coups de charge.

MICROSEISMIC MONITORING AND STUDIES AT KIDD CREEK MINES

INTRODUCTION

Presently, Kidd Creek produces 17 000 t of sulphide ore daily from its No. 1 and No. 2 underground mines, at a tonnage ratio of three to one. Both mines employ blasthole open stoping with delayed backfilling.

Stope production has reached the 2000 level, 610 m horizon, in No. 1 mine and the 3400 level, 1040 m horizon, in No. 2 mine.

Although underground operations have not encountered any serious rockburst problems, several incidents of seismic disturbance have occurred and affected production scheduling.

The first occurrence of seismic activity during the pit bottom recovery in 1974, provided impetus for more careful mine planning with rock mechanics concerns, especially in dealing with mining at a deeper level.

To understand rockburst phenomena rock mechanics studies have been carried out in the mines, including determination of in situ field stress and physical properties of rock, monitoring of abutment stress changes due to stope excavation and backfilling, and microseismic monitoring. Data obtained from those studies have been incorporated in mine planning to design an optimal mining method and sequencing.

A successful mining practice used in extracting ore between 2600 level and 2800 level has led us to believe that an optimal mining method can eliminate, or if not possible, at least alleviate the occurrence of rockbursting.

MICROSEISMIC MONITORING SYSTEMS

A SINCO MS-2 Geomonitor, as shown in Fig. 8.1, has been used in the mine for monitoring and recording underground seismisicity for the past five years. The instrument is battery operated and can be installed in any location to record seismic events continuously up to 48 hours. The device consists of the following units:

a) Eight detectors with each detector containing a piezoelectric transducer and a preamplifier, with flat frequency responses from 4 Hz to 17 kHz. The nominal overall voltage gain is 126 db (2×10^6). The transducer converts mechanical vibration into electrical signals in response to the particle acceleration of the motion.
b) Eight plug-in amplifier modules, all of which are contained in a pressurized metal console. The module is composed of a signal amplifier with four selected gains; a bandpass filter with four selectable steps at 10 Hz, 100 Hz, 1 kHz, and 10 kHz; one triggering level control; and an analog output jack for tape recording.
c) An eight-channel event recorder for recording the number of seismic events which exceed a pre-set intensity level, expressed in pulse form.
d) A set of earphones which can be plugged into one of the two-channel earphone jacks for listening to seismic events.

Rock noise or seismic events can be retrieved, analyzed and counted from a tape recording produced by the geomonitor. The geomonitor detects any vibration with frequency in the audio range beyond a pre-set level. As a result, any machine noise or cultural disturbance is liable to be recorded, thereby impinging the fidelity of information. Monitoring of seismicity with the geomonitor, therefore, has been limited to quiet areas free from mining activities.

Another microseismic monitoring device – the McPhar Rock Stress Monitor (Fig. 8.2) – has been used to supplement the geomonitor for monitoring seismic events in high background noise areas. The stress monitor responds only to acoustic emissions at frequencies above 30 kHz, thus eliminating the interference of most machine noises.

The device is a single channel unit designed for:

1. Detecting high frequency acoustic emissions generated by dynamic changes in the underground structure.
2. Processing and analyzing data for display and recording.
3. Activating visual and sound indicators when pre-set limits are reached for audio-visual warnings.

The single, hand-portable unit consists of the following components.

1. A lithium sulphate sensor, which translates ultrasonic pulses into electrical signals that are preamplified and sent to the main assembly for conditioning. The sensor responds to the particle acceleration of seismicity.
2. A detector module, which contains a gain control and a trigger level control to provide a means of filtering out extraneous background noise.
3. A processor module, which contains a computer circuit that performs integration on the signals to display data on a periodic basis. An event/stress factor switch selects either the total number of acoustic events, or the total stress factor of those events detected during the previous one minute interval for digital display. The stress factor is defined as the ratio of the energy level to the number of events in a one minute period, equivalent to the average seismic intensity of each event.
4. An indicator module provides a yellow light to signify a high stress level when the energy level exceeds a pre-set value. A red light indicates an over stress level when the stress factor exceeds a pre-set level.
5. A rechargeable battery supplies power to the system for up to ten days of continuous operation.

A two-channel strip chart recorder can be used with the monitor to transcribe the number of acoustic events, or the level of the stress factor, per minute, on the paper.

DESCRIPTION OF SOME CASE STUDIES

1. In 12334 Crosscut

The 12334 crosscut was located in the 1234 rib pillar between two backfilled stopes as shown in Fig. 8.3. On June 3, 1981, shock disturbances occurred in the crosscut, associated with an expulsion of approximately 5 t of drift wall rock/ore. Spalling also appeared in the stope wall on the opposite side of the pillar across from the bumped area.

Upon investigation it was found that the crosscut was 10 m (30 ft) underneath the blasted crown pillar, which led upward to the pit bottom. The vertical stress component was negligible. The pillar, 24 m wide by 60 m long by 67 m high, had become a remnant rock mass between the footwall and the hanging wall. This introduced a high lateral stress field, with an assumed stress concentration factor of 2.8, resulting in a stress level of 58 MPa (8.4 ksi).

The pillar was composed mainly of sulphide ore, especially massive sphalerite at the expulsed area. Sphalerite ore in the mine has been recognized as a relatively brittle and burst prone rock type. A predominantly conjugated joint set was observed at the site.

Based on the geometry of the pillar and the rock/ore type, the pillar strength using an empirical formula (1) was estimated to be 62 MPa (9.0 ksi). This yielded an estimated stress-strength ratio of 0.95 at the 12-3 sublevel, indicating a potential for bursting or yielding failure to occur, depending upon rock type. During the disturbance period, a crosscut on the 12-2 sublevel was quiet. This could be attributed to the effect of confining pressure exerted by the backfill on the pillar at the 12-2 sublevel, reducing the stress-strength ratio to an acceptable level of 0.7.

Microseismic monitoring was carried out in the crosscut using the SINCO Geomonitor. A Hewlett Packard strip chart recorder was also used, with two geophones to record the seismic intensity. Figure 8.4 shows the composite data recorded during the period of June 12-15, 1981.

The pillar was shattered between the 12-2 and 12-3 sublevels by blasting a row of small diameter holes, drilled to a depth of 30 m along the hanging wall, with satisfactory destressing results.

2. In 20234 Drill Drift

The 2034 stope is located at the south end of the orebody between the 600 m (2000 ft) and 510 m (1700 ft) horizons. The mining sequence of the stope was planned to retreat towards the south, with the stope width tapering along the ore strike.

Initially, the stope was opened 18 m (60 ft) wide and 15 m (50 ft) long, along the strike. In early April 1984, when the stope muck level was low, occurrences of snapping ground were reported in the 20234 drill drift. The drift (Fig. 8.5) was excavated through the ore zone to the south ore boundary.

One set of IRAD gauges, vibrating wire stress metres for measuring stress changes in boreholes, had been installed in the drift, 12.5 m away from the stope face. During the seismic disturbance period, the gauges revealed a substantial increase in the tangential stress level, which finally reached a peak value of 76 MPa, as shown in Fig. 8.6 (1). Afterwards, it was noted that several blastholes at the site were severely fractured and required redrilling.

The McPhar Rock Stress monitor was tested in this area during the seismic activity. The monitored result indicated that the frequency of seismic events was six times higher than the ambient level, however, with low stress ratio readings at the location near the IRAD gauge site.

Up to now, the McPhar system has not been fully evaluated, as to its capability of providing precursor warnings of ground failure, and its effective range of monitoring. Further field tests will be done in the near future.

3. Microseismic Monitoring of Rock Samples

The laboratory testing of microseismicity on rock samples was undertaken to find the threshold of internal cracking and the duration of microseismicity under loading. A rock sample was loaded in various increments and held at each stress level, while microseismic counts were taken with the McPhar monitor, until failure of the specimen occurred. Testing with an aluminum block indicated that the McPhar monitor was immune from the press machine vibration.

Figures 8.7 and 8.8 illustrate typical preliminary results obtained from testing cherty breccia and andesite samples. Pronounced seismic activity commenced when the load reached 60% of the ultimate strength of a cherty breccia sample, and 66% of the failure of load of an andesite sample. Both showed occurrences of seismic activity during the process of loading, and disappearance of activity at constant loading.

The maximum activity took place when the load reached 90% and 80% of the ultimate strength of the cherty breccia and andesite specimens respectively.

SOME BURST CONTROL CONCEPTS USED AT THE MINES

1. A zone of highly concentrated abutment stress was found from measurement (2) in competent rock surrounding an opening as shown in Fig. 8.9. For a single opening, the abutment stress exists in the wall, at a distance equivalent to one half of the opening width from the opening face. The high stress zone is identified as one of the potential burst prone areas. An effective de-stressing program, therefore, should be conducted in the zone or beyond it.
2. Shifting of abutment stresses in sulphide ore was shown in Fig. 6, at a loading rate of 65 MPa per 10 days without causing violent rock failure. This could be attributed to the slow strain energy release rate. The spatial rate of energy release should be recognized in space and time (3) in rockburst studies.
3. Mining in No. 2 mine between the 780 m and 840 m horizons has been very successful in terms of bursting control. This was accomplished by mining from the central zone, without leaving any remnant rib pillars to compound the stress concentration.
4. Consolidated backfill provides lateral confining pressure to the adjacent wall, thereby enhancing its rock strength (4). This, in turn, controls the energy release rate and rockburst incidence as well.

CONCLUSIONS

1. The monitored seismic data from the Geomonitor was found to be useful in helping to evaluate ground conditions. The instrument, however, could not differentiate seismic events from cultural noise such as drilling, blasting, scooptrams, etc.
2. The McPhar stress monitor is capable of filtering out machine noises, and registers only high frequency seismic events. Due to the high attenuation rate of ultrasonic waves, the detection distance may be limited.
3. Laboratory testing indicated that seismic activity occurred only during the process of incremental loading, and that the failure of a specimen was preceded by a maximum of seismic events.

ACKNOWLEDGEMENTS

Thanks are due to the management of Kidd Creek Mines for permission to present this paper, and the members of Rock Mechanics group for data compilation. J. Gallagher carried out the laboratory testwork.

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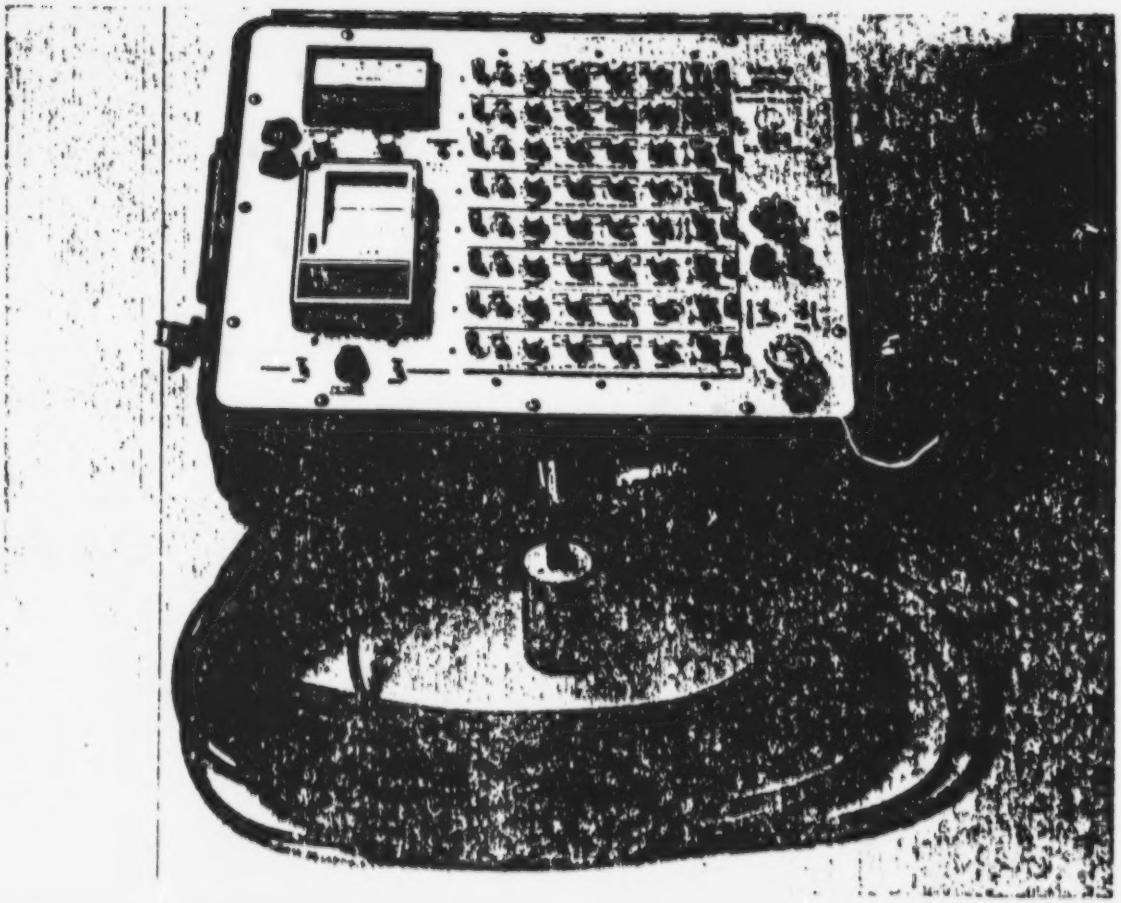

Fig. 8.1 — SINCO MS-2 geomonitor and transducer

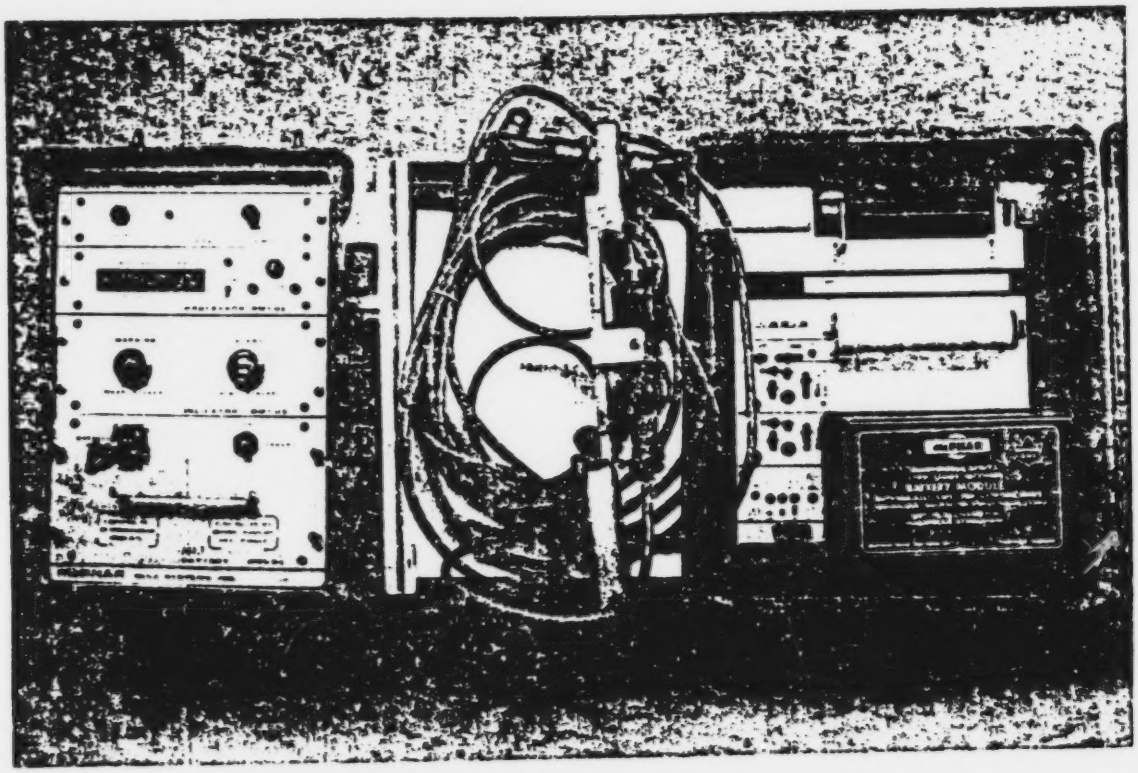

Fig. 8.2 — McPhar Rock Stress monitor

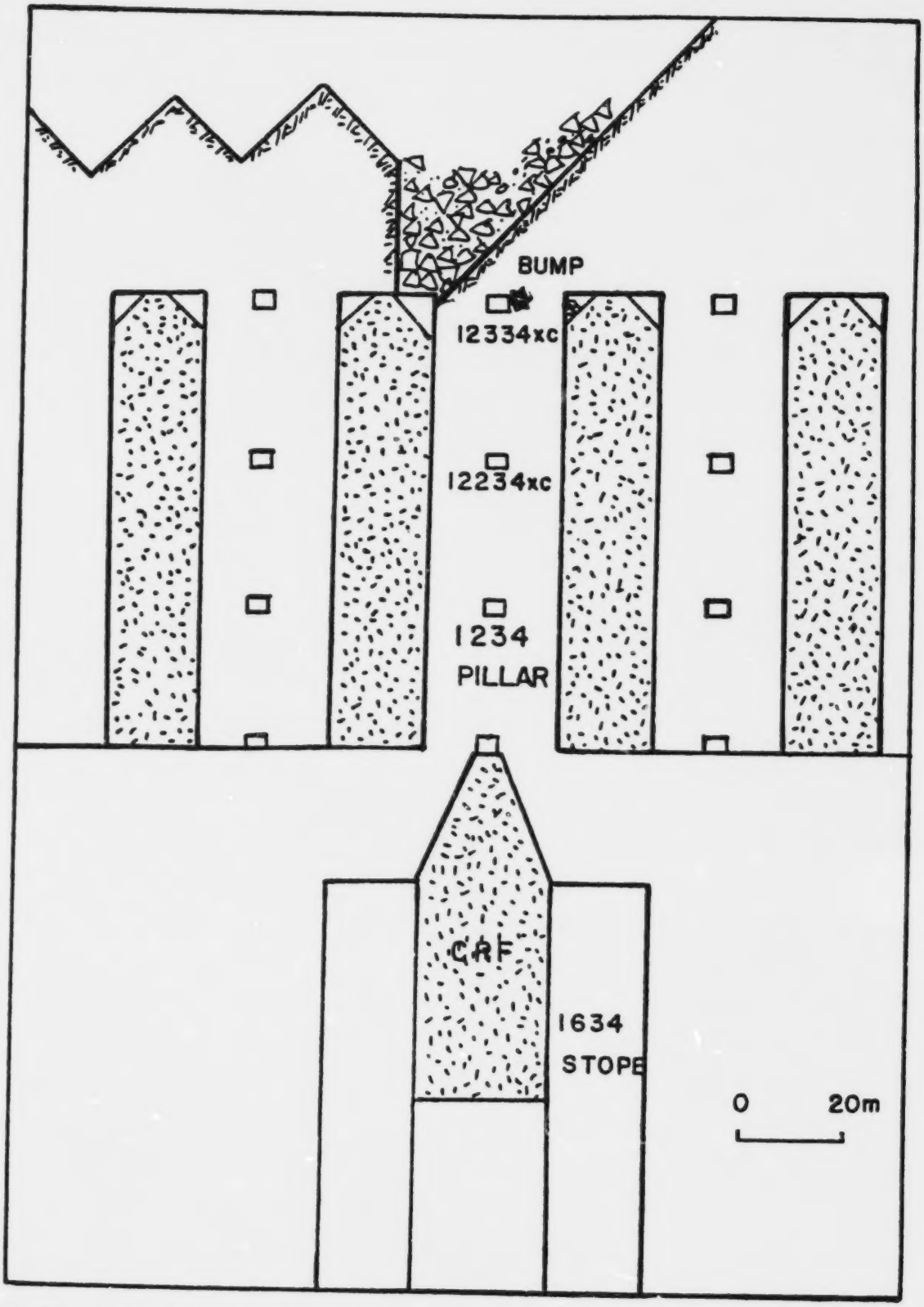

Fig. 8.3 — A longitudinal section of 1234 pillar

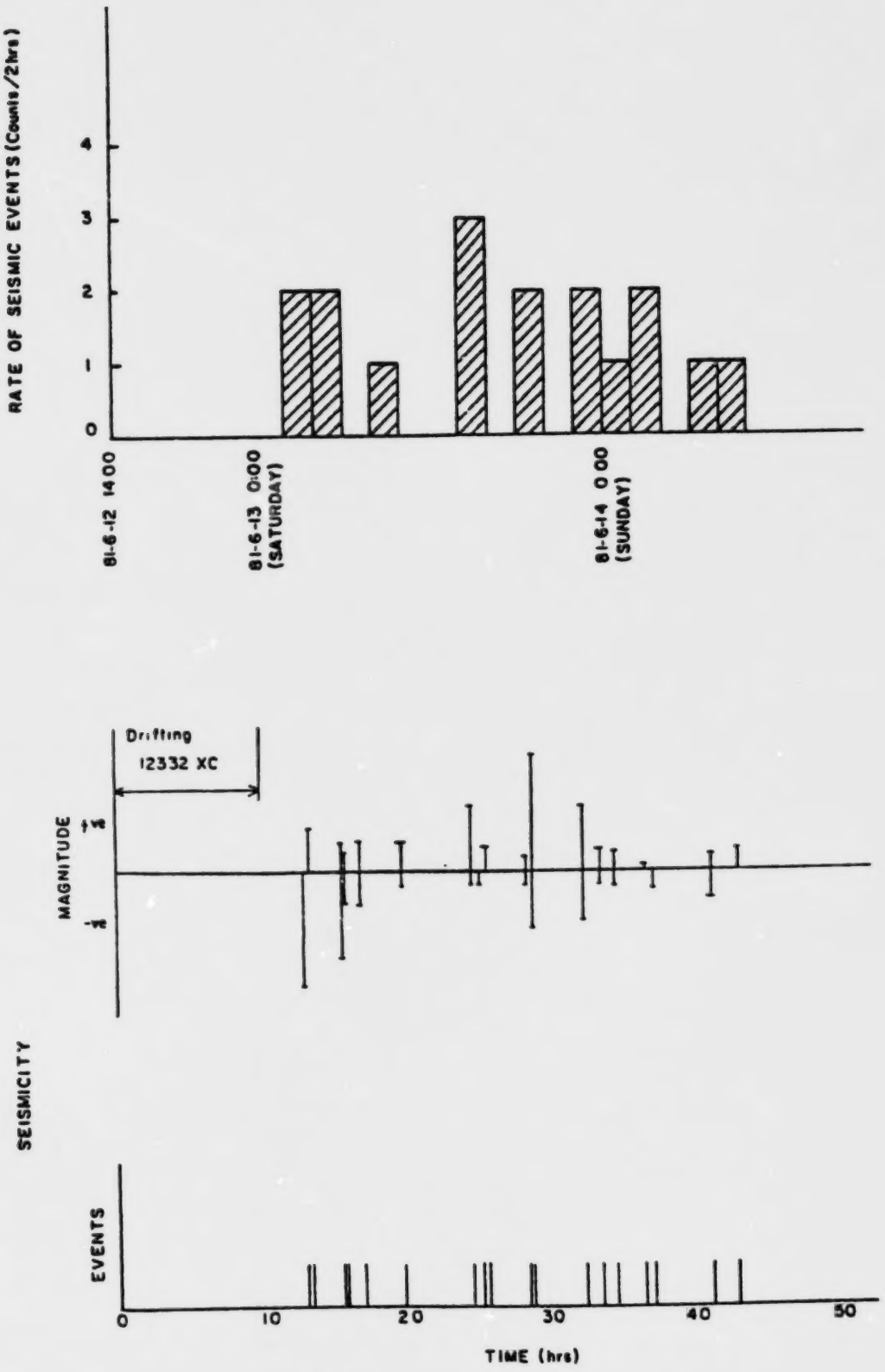

Fig. 8.4 — Seismic events vs time in 12334 crosscut

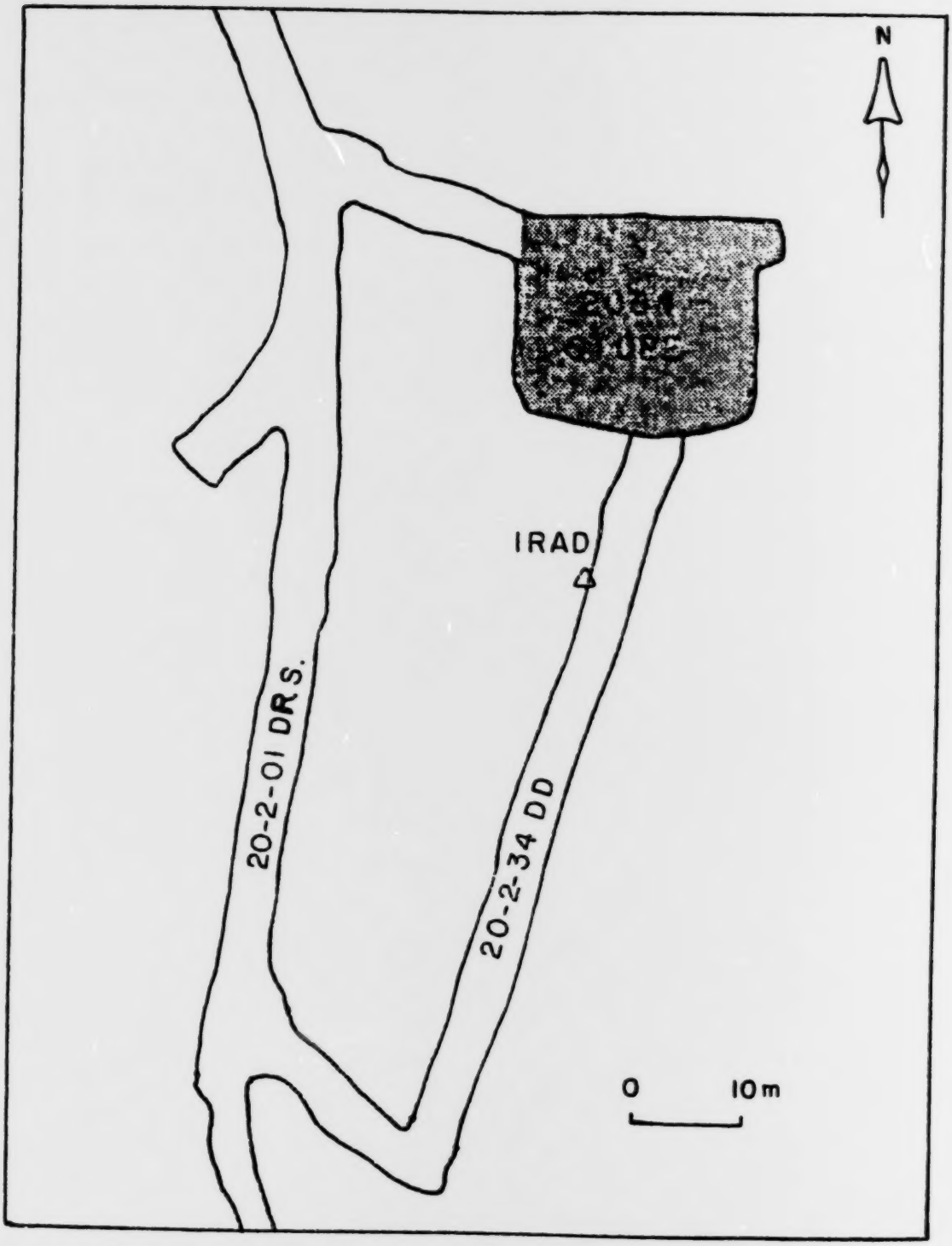

Fig. 8.5 — Seismic monitoring in 20234 drill drift

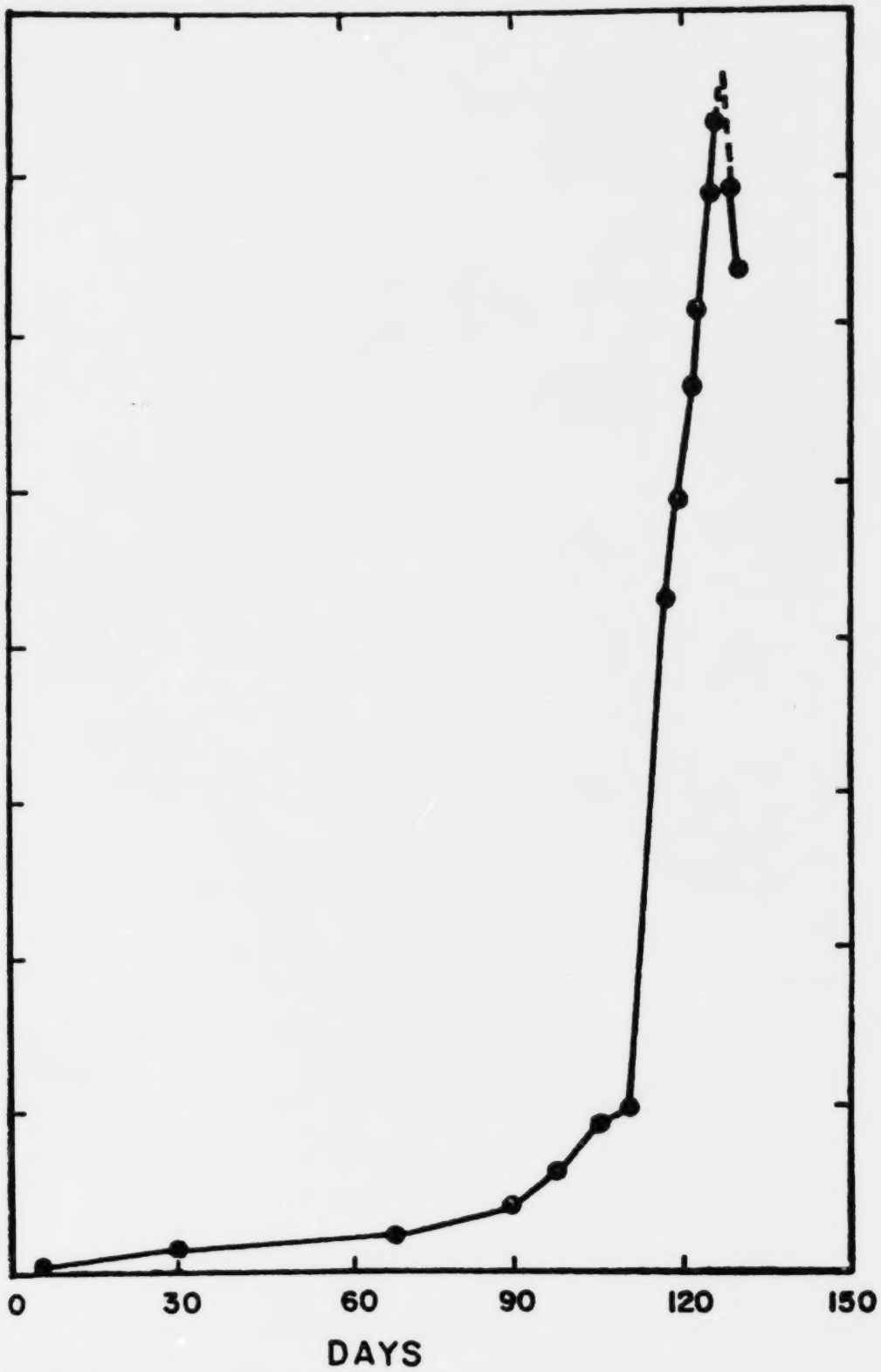

Fig. 8.6 — Abutment stress change vs. exposure time

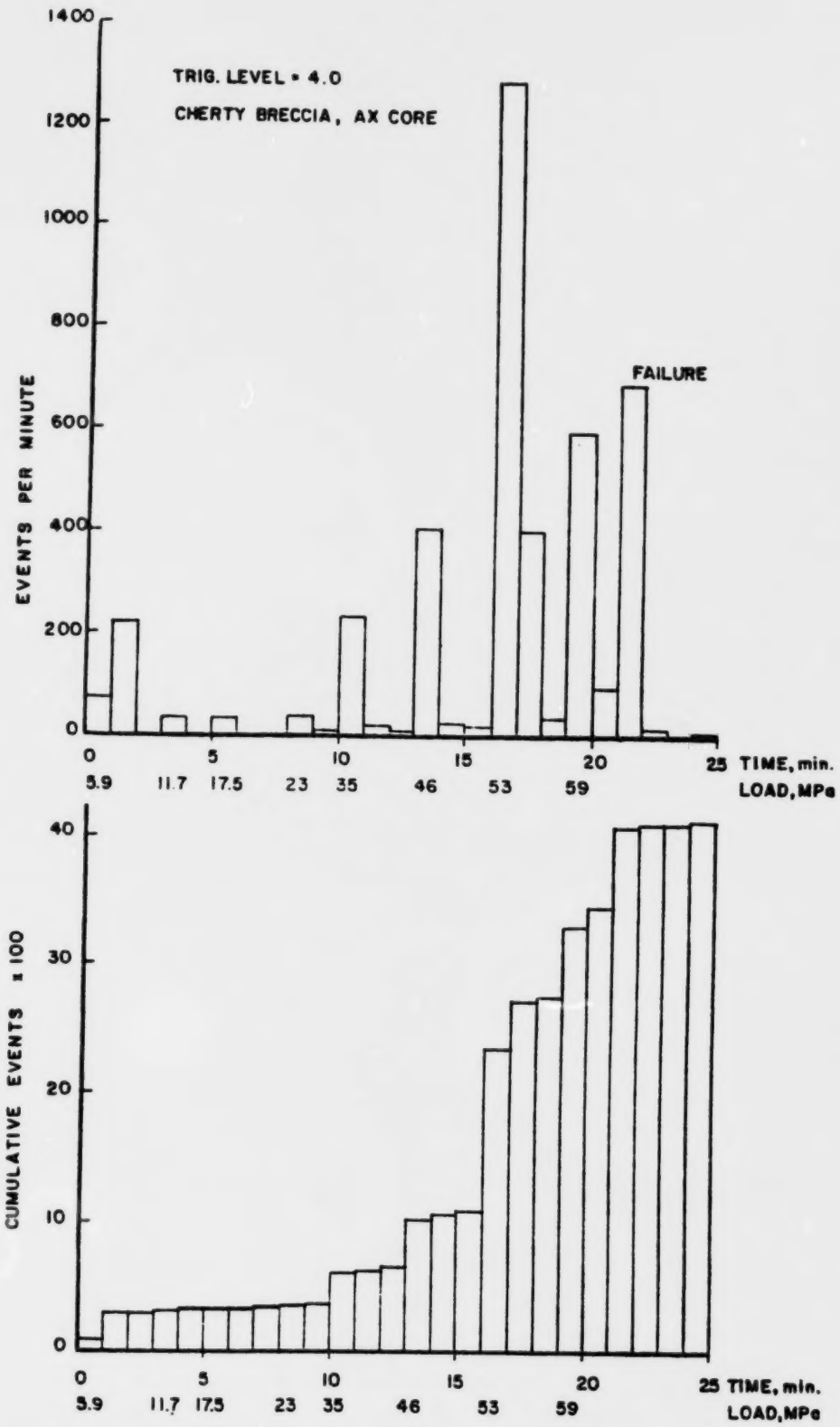

Fig. 8.7 — Seismic events vs load/time of Cherty breccia sample

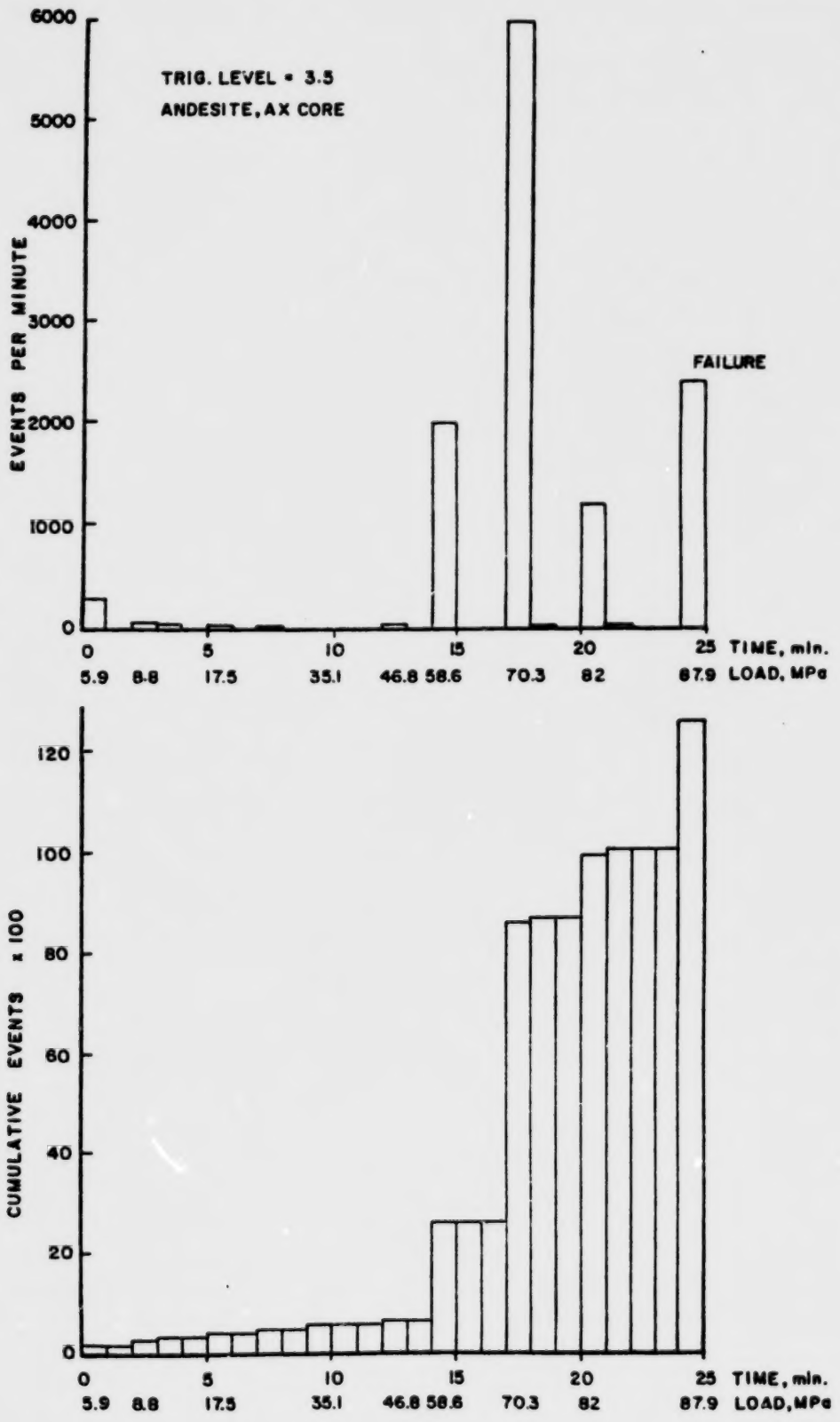

Fig. 8.8 — Seismic events vs load/time of andesite sample

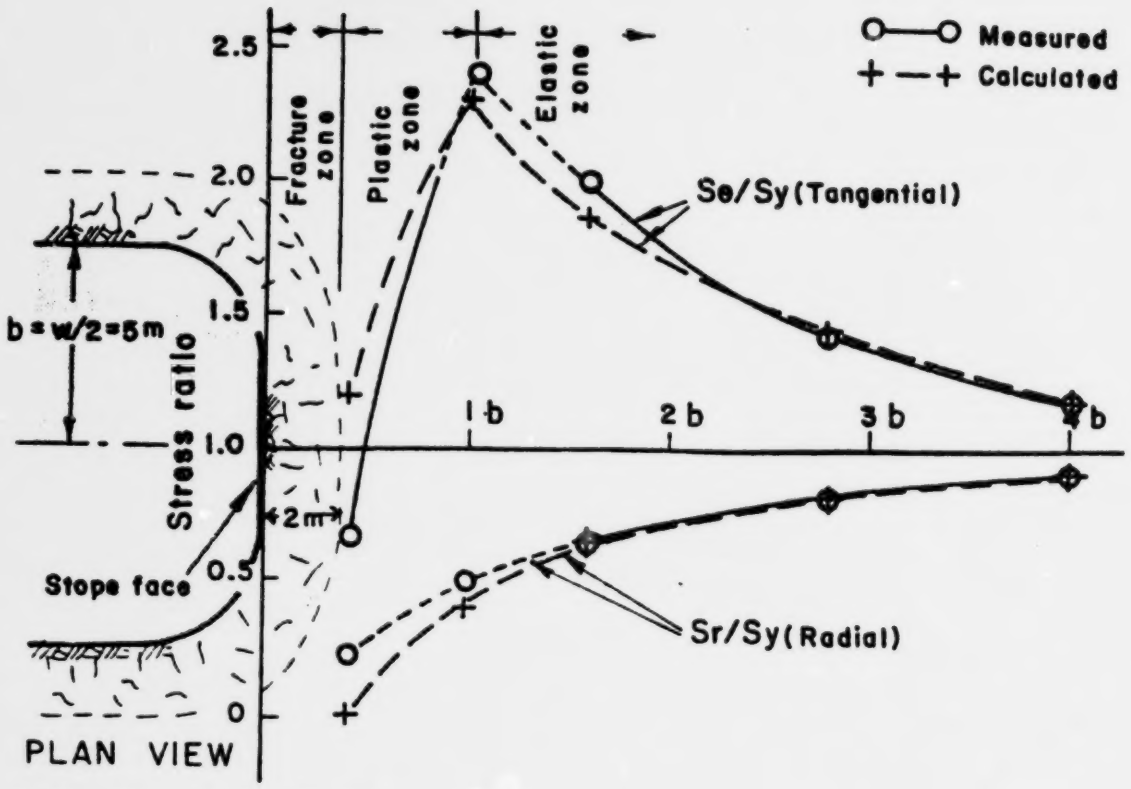

Fig. 8.9 — Abutment stresses in relation to stope face

A POTENTIAL APPLICATION FOR A MULTICHANNEL MICROSEISMIC SYSTEM AT DENISON MINES

G. Hunt
Denison Mines Ltd.

ABSTRACT

In order to recover ore from the large rib pillars in areas of the mine where mining activities have been discontinued, it is believed that conventional pillar robbing techniques, in conjunction with a backfill mining program, can be employed successfully. The recovery plans require a full and thorough assessment of ground stability in the areas to be mined, and the areas must be monitored during and following the completion of the recovery operations.

Inspections in these areas are presently made on a periodic basis to assess ground conditions. Generally, these inspections reveal very little ground movement having taken place, and this is attributed to the pillar safety factors being (on average) much higher than required. However, there are isolated areas where pillar spalling is evident. In such areas it can be demonstrated that the spalling is due to having already obtained what is considered as optimum extraction. Consequently, there is a need to monitor the areas of pillar deterioration. However, we must first carefully evaluate and plan a suitable monitoring program.

The potential of a multichannel microseismic monitoring system is under consideration at Denison and the rationale for selecting such a system is reviewed in this paper.

A précis of the kind of results that can be expected and an appraisal of multichannel microseismic systems, based on past experience with the Electro Lab 250 MP system, is presented.

APPLICATION POSSIBLE D'UN SYSTÈME MICROSISMIQUE À PLUSIEURS VOIES À LA DENISON MINES

G. Hunt
Denison Mines Ltd.

RÉSUMÉ

Afin de récupérer le minerai des grands piliers abandonnés des parties de la mine où l'exploitation a cessé, on pense qu'il serait possible de combiner avec succès les techniques de dépilage classique et un programme de remblayage. Les plans de récupération exigent une évaluation complète et détaillée de la stabilité du sol dans les zones devant être exploitées; ces zones doivent en outre être surveillées pendant et après la récupération.

Nous procédons actuellement à l'examen périodique de ces zones en vue d'évaluer l'état du sol. Généralement, ces vérifications révèlent qu'il n'y a eu que très peu de mouvements et cela est attribué aux facteurs de sécurité appliqués aux piliers, qui sont (en moyenne) beaucoup plus élevés que ceux exigés. Il existe cependant certaines zones isolées où l'effritement des piliers est évident. Dans de telles zones, il est possible de démontrer que l'effritement est le résultat d'une extraction optimale déjà obtenue. Par conséquent, il est nécessaire de surveiller les zones où les piliers se détériorent; nous devons néanmoins d'abord évaluer et planifier en détail un programme de surveillance convenable.

Nous étudions les possibilités d'utiliser à la Denison Mines un système de surveillance microsismique à plusieurs voies et nous examinons dans la présente communication la méthode permettant de choisir un tel système.

Nous présentons un résumé des types de résultats que nous pouvons obtenir et une évaluation des systèmes microsismiques à plusieurs voies, fondés sur l'expérience acquise avec le système Electro Lab 250 MP.

A POTENTIAL APPLICATION FOR A MULTICHANNEL MICROSEISMIC SYSTEM AT DENISON MINES

INTRODUCTION

The general geology of Elliot Lake includes a sequence of metamorphosed Huronian sediments unconformably overlying a granitic and metavolcanic basement complex.

Uranium bearing reefs are confined to conglomeratic units at or near the base of the Huronian section in the Matinenda Formation of the Elliot Lake group. The conglomerates are generally sheet-like, but often lens or interfinger one another, and are affected by local pre-existing topography.

The orebody in the area of Denison Mine consists of up to five stratigraphically separate quartz-pebble conglomerate reefs lying in the north limb of the regional Quirke Syncline (Robertson 1968). The two major reefs, 'A' and 'B', constituting the 'Main Reef', lie at depths between 800' and 3000' and dip at approximately 20, over strike length of 15 000 feet. Each is approximately 10 feet thick, and the two are separated by 8-10 feet of relatively lower grade interbedded quartzites. The mine is transversed by several near-vertical diabase dykes up to 60 feet in thickness.

Three 'upper reefs' ('D', 'E' and 'F') lie at approximately 150 feet above the Main, and geologically are more variable in character. They are less intensively mined. The majority of the Denison property currently in production lies beneath Quirke Lake which has average depth of 250 feet.

Denison uses a room and pillar mining method, which is well suited to the tabular type orebody. The mining has become highly mechanized over the years and presently 65% of the total production comes from jumbo stoping. However, when Denison began production in May 1957, stoping was primarily by jackleg. In this manner, the majority of the area north of the Keyes Dyke (Fig. 9.1) was mined out. Mining progressed quickly across what is referred to as the north country (the area north of the Keyes Dyke up to the Rio Algom property). By the early 1970's the stoping blocks were nearly completed, however, ore reserves had been left behind in the wide pillars and sills. Although conventional second pass recovery methods have been used to take many of the sills in these stoping blocks, the rib pillars are well intact. From a production point of view it is desirable that methods for recovering ore in the rib pillars be developed. Plans for rib pillar recovery are mixed between conventional and backfill methods and include, as well, an extensive spray leaching program. All of this brings about the need for increased instrumentation monitoring to be considered, and microseismic monitoring has certain possibilities.

For presentation purposes, the cross-label portions of Fig. 9.1 indicate the areas of concern.

Objectives of Multichannel Microseismic Monitoring

As is true of every instrumentation program, specific objectives must be outlined prior to selection of the instruments. The objectives must be kept in line with the goal of mining, which is to obtain a high level of production with a high level of safety.

With this in mind, some of the pertinent objectives are as follows:

1. The system must give an accurate indication of the level of stability in the region being monitored within a reasonable time frame.
2. The system must accurately locate seismic events. A measure of the amount of energy released by an event would be useful.
3. The areas to be monitored are large and in separate pockets, therefore the system must be capable of covering large areas without loss of signals or suffer from excess interference.
4. The operation of the system must not be affected by mining progression and distinctions between mining activities and ground movement must be made.

5. Seismic event records must be continuous, the data transmission must be immediate and readily understood by mine personnel.

These are the principal objectives that are foreseen and a multichannel microseismic system covers these objectives. However other factors involved must also be considered.

Associated Factors

The following factors also warrant some attention:

1. The locations of the geophones are flexible. The density and size of the array is variable. Installations are not difficult.
2. Cable installation is not troublesome. Cables must not be located where pillar slots are planned, and it must be remembered that cabling costs are very significant.
3. Geophones can be selected from several types having different frequency responses to facilitate different aspects of monitoring or research.
4. Unidirectional or multidirectional integrators can be added to the system to enable accurate energy calculations.
5. Alternate system software packages exist for the purposes of data recording and presentation.

In addition, the comparison to other microseismic techniques will also assist. Denison's experience with the single channel seismograph, the geomonitor and stress alert device, as well as with the 250 MP system is useful in the decision making process.

Results to be Expected

Prior to system selection some results must be anticipated. For the study areas noted in Fig. 9.1 and with the recovery plans outlined earlier, it is feasible that the multichannel system would (in time) develop a reasonable estimate of ground stability. Productivity could increase if the ground stability was found to be favourable. Improved safety should also result from continuous records of the seismic events in problem areas. Work-places could be selected on the basis of low seismic activity and related information.

A Final Appraisal

From the knowledge that has been gained thus far by the application of microseismic techniques at Denison, the following appraisals are made:

1. An increased awareness of seismic activity does occur. This has a positive effect on ground control, but must be tempered with other corroborating data before taking any action.
2. Through the process of calibration, the mine personnel can begin to discriminate between events and begin to realize the importance of the more significant events.
3. Many of the bugs in previous microseismic systems have been corrected in recent years, and this has led to more useful applications.

CONCLUSION

With respect to the possible application of a multichannel system at Denison (for the purposes described in this paper) attention must be paid to other quantitative types of measurements (such as convergence readings) before any decision is made. The role of microseismic monitoring will no doubt become increasingly important. Denison is keenly aware of the potential of microseismic monitoring and appreciates the efforts made by industry and government sectors in this field.

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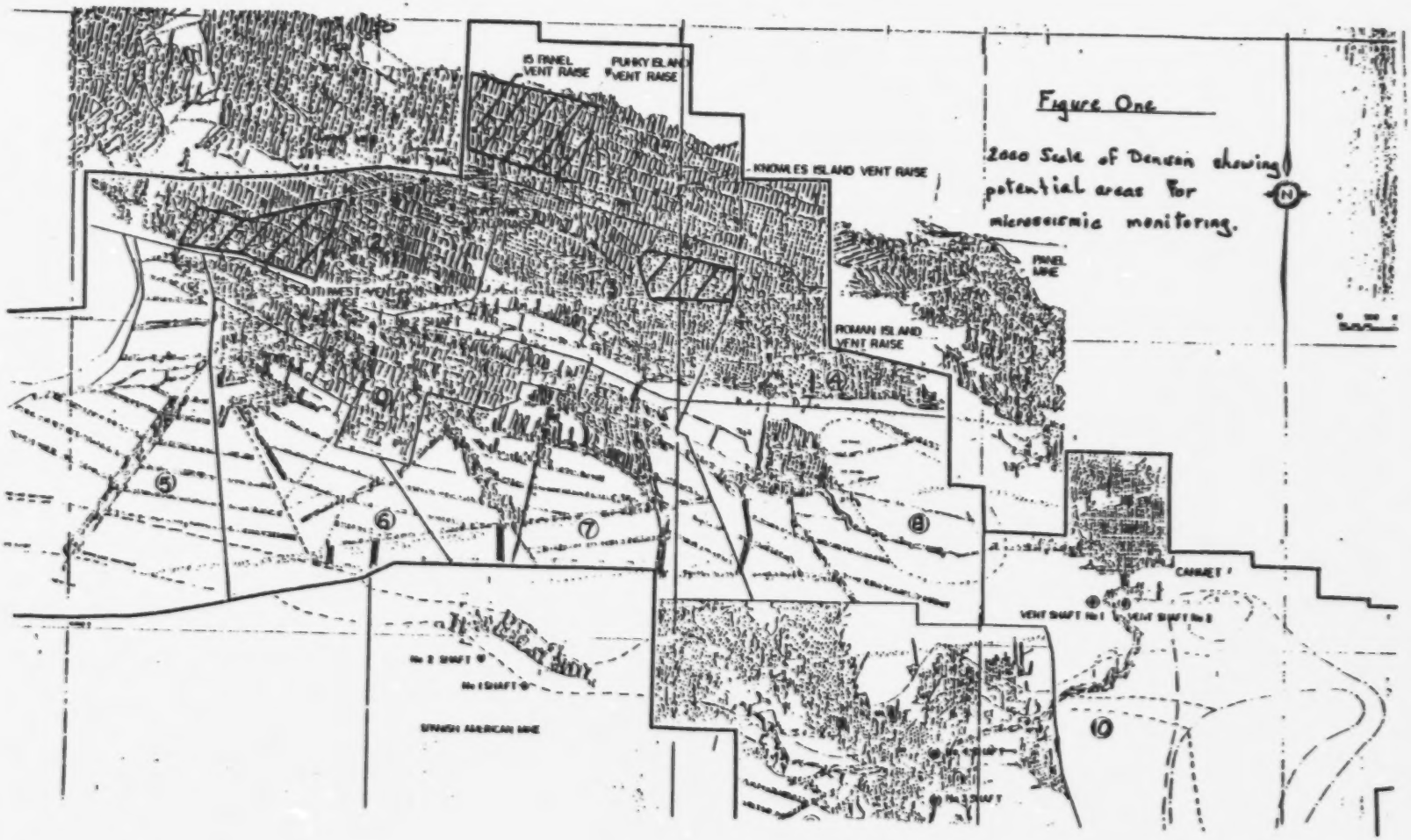

Fig. 9.1 — 2000 scale of Denison showing potential areas for microseismic monitoring

ACOUSTIC EMISSION MONITORING OF SLOPE STABILITY IN OPEN PIT MINES

T.V. Vladut
Calgary Coal Research Laboratory
CANMET, Calgary

ABSTRACT

Pit slope stability is a common problem in open pit coal mines in the Rocky Mountains region of Canada, where much of the coal occurs in steeply dipping seams. It is generally thought that early indications of potentially unstable ground conditions would facilitate the development of stripping ratios that could reduce or eradicate slope stability problems. This paper discusses the role of microseismic monitoring, as an aid to the routine system, for the provision of early warning data.

SURVEILLANCE PAR L'ÉCOUTE DES ÉMISSIONS ACOUSTIQUES DE LA STABILITÉ DES TALUS DANS DES MINES À CIEL OUVERT

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CANMET, Calgary

RÉSUMÉ

L'instabilité des talus des mines à ciel ouvert pose un problème commun dans les mines de charbon à ciel ouvert dans les Rocheuses canadiennes où une grande partie du charbon se présente en veines à forte pente. Nous pensons généralement que des premières indications d'une instabilité éventuelle du terrain permettraient la mise au point d'une méthode de calcul des rapports de dépilage susceptibles de réduire ou de faire disparaître les problèmes d'instabilité des talus. La présente communication examine le rôle de la surveillance microsismique comme complément au système de surveillance systématique afin d'obtenir des données de pré-alerte.

ACOUSTIC EMISSION MONITORING OF SLOPE STABILITY IN OPEN PIT MINES

SUMMARY

Open pit operations often face the problem of the pit slope instabilities resulting in production stoppage and risk to personnel and equipment. Slope instability is a common operational problem in coal mines in the Rocky Mountains where coal occurs in steeply dipping (40° – 75°) seams. A certain advantageous stripping ratio could be achieved by coping with the risks through early warning of instabilities.

The objective of the field tests undertaken at Cardinal River Coal Mines as a cooperative effort by the operator and a joint USBM-CANMET team, was to evaluate the contribution of the microseismic measurement as an aid to the routine monitoring system (EDM). The microseismic system for slope monitoring was developed at the Denver Research Centre (USBM-RI #8641/1982). The monitoring system was tried for 28 days in June – July 1984. The image of microseismic activity variations has a good correspondence with the overall movement of the slope (Fig. 10.1 and Fig. 10.2). The geomechanical significance of the events location is in analysis stage and it is mainly related to the nature of the slope movement controlled by the weak character of the rock material ($E \cong 4$ GPa, $RQD \cong 0$). Some further steps are related to post experimental calibration, identification of the nature of potential erratic inputs ("lightening"). Further utilization may be related to the necessity of an automated more sophisticated data processing means which may be used at the site in conjunction to data collection, for immediate decision in the early warning procedure.

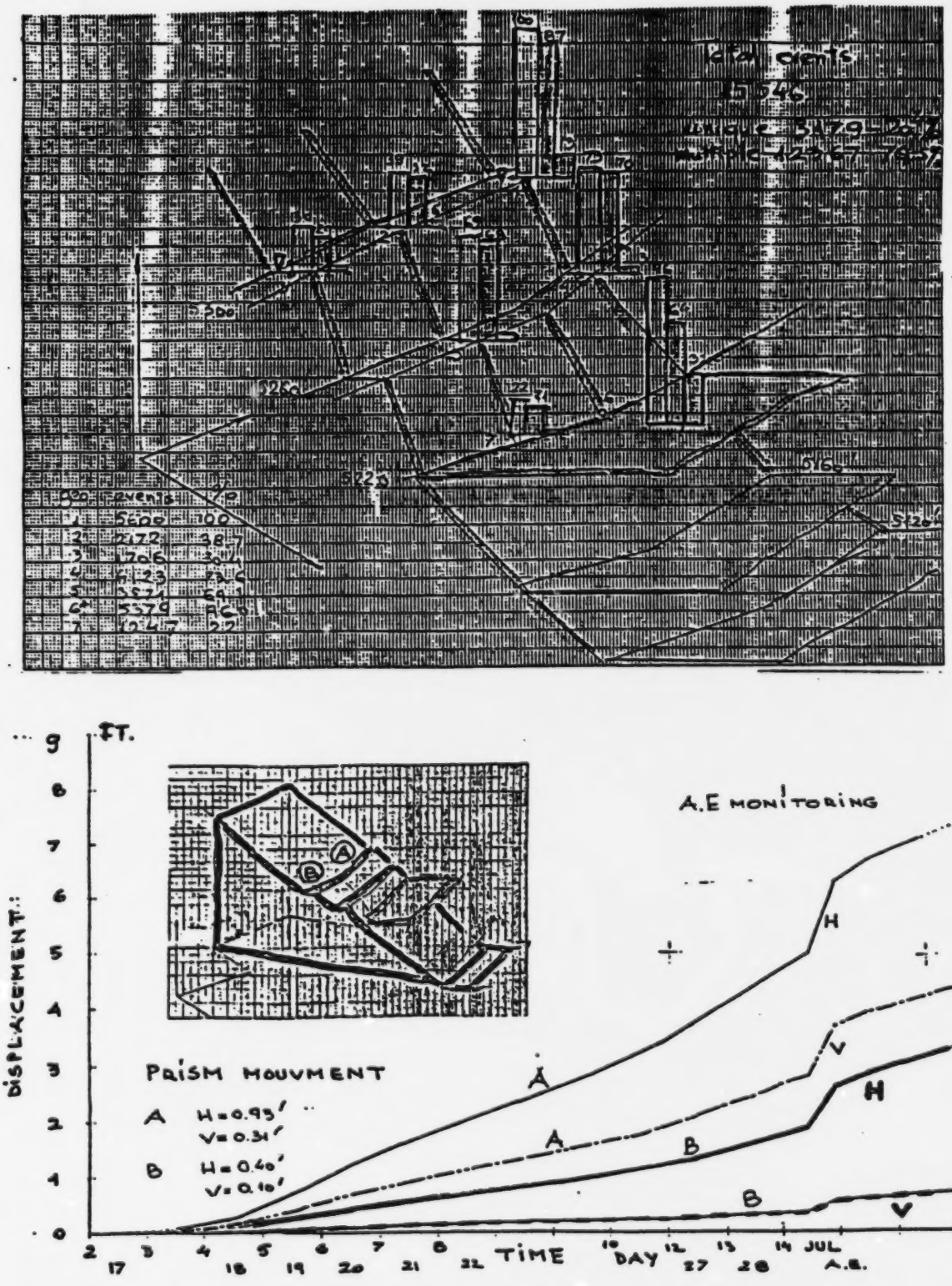

Fig. 10.1 — Distribution of multiple and unique type of events. Correlation of events and slope movement.

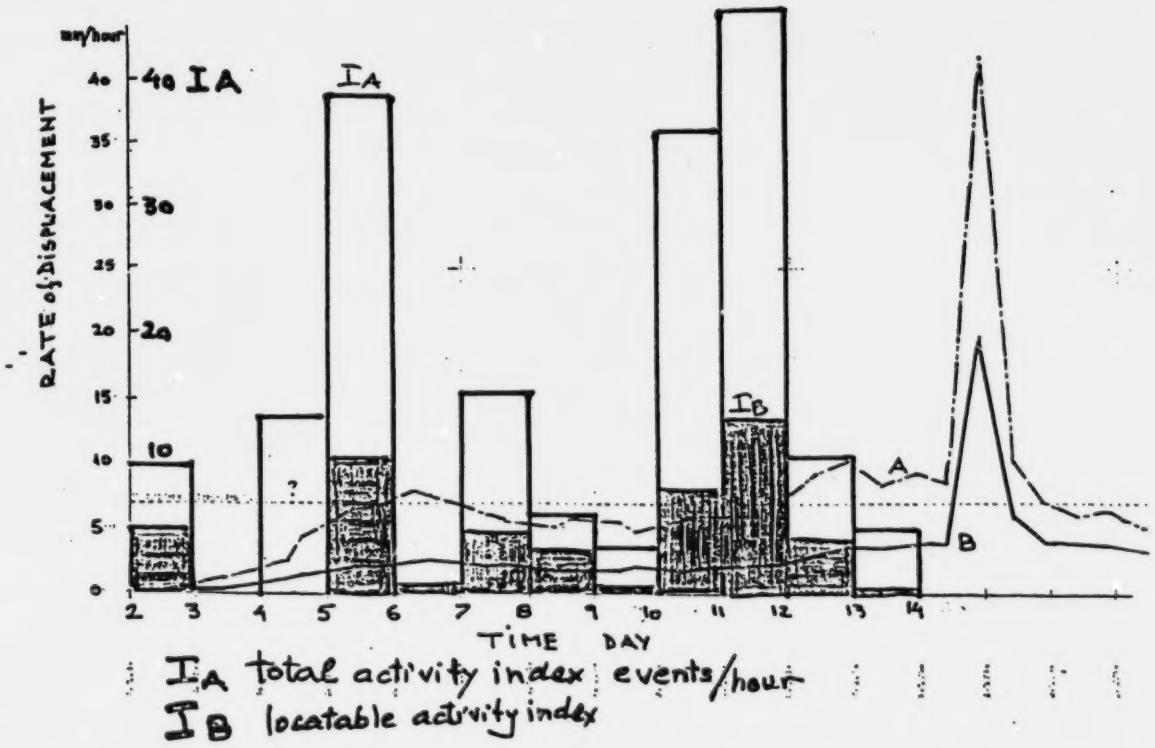

Fig. 10.2 — Distribution of activity and rate of displacement of the monitored slope.

NOTES ON ROCKBURST PROBLEMS AT MACASSA MINE

J. Cook
Lac Minerals Ltd.

ABSTRACT

The Macassa Mine owned and operated by the Lac Minerals Ltd. group is situated in the Kirkland Lake area of Northern Ontario. Future mining will take place at depths of 7000 ft and previous experience has shown that the mine can expect to meet a diversity of rockburst problems, from small-scale spalling to large rockbursts, in which whole stopes could be lost. This presentation of notes describes the considerations and monitoring programs used by the Lac Minerals Ltd. group to combat the ground control problems experienced at their properties.

PROBLÈMES CRÉÉS PAR LES COUPS DE CHARGE À LA MINE MACASSA

J. Cook
Lac Minerais Ltée

RÉSUMÉ

Le groupe Lac Minerais Ltée exploite la mine Macassa dont il est propriétaire; cette mine est située dans la région du lac Kirkland, dans le nord de l'Ontario. L'exploitation future se fera à des profondeurs de 7 000 pieds. L'expérience a montré qu'il se posera vraisemblablement différents problèmes de coups de charge, dont l'amplitude pourrait varier d'effritements à petite échelle à la déstabilisation de chantiers en gradins. La présente communication décrit les facteurs considérés et les programmes de surveillance utilisés par le groupe Les Minerais Lac Ltée pour surmonter les difficultés de stabilisation des sols éprouvées sur ses propriétés.

NOTES ON ROCKBURST PROBLEMS AT MACASSA MINE

Rockburst problems in the Kirkland Lake area and Macassa Mine, in particular, have been described recently in a paper presented to the Rockburst Symposium in London, England, in October 1983. Generally, the history of rockbursts in the Kirkland Lake Camp is well documented but because of scattered mining, Macassa has been relatively untroubled. However, new mining areas at Macassa are such that a larger percentage area of the ore bearing horizon will be mined. This area is currently being approached by a new 7270 ft deep shaft.

The rockburst problems at Macassa vary from small scale 'strain bursts', when pieces fly off a development face, to very large bursts which involve whole stopes or more. For example, the last major burst at Macassa, in March this year, affected several levels and several stopes, and measured 3.1 on the Richter scale. Bursts of every sort of magnitude in between the very small 'strain bursts' and these large bursts take place frequently. By 'bursts' we mean explosive fracturing of the rock and in this respect we do not differentiate between the small scale bursts and the very large scale bursts. It is merely a matter of scale and the amount of energy involved.

We regard the energy concept as important and part of our work at Macassa is aimed at improving the sequence of mining and thus equalizing the rate of energy release. However, regardless of the best sequencing there is always energy released that causes fracturing, and sometimes this fracturing is violent. In our opinion, the key to whether the failure is violent or not is well demonstrated by theoretical work in the loading machine. Stiff rock loaded with a soft machine will explode. When the machine is stiffer, then the rock failure will be peaceful. Within the ore zone, and in the immediate hanging wall and footwall at Macassa, there are significant differences in the rock properties, particularly in the moduli of the varying rock types. There are three different rocks, tuff, porphry and syenite, and within each of these rocks there are many variations as the quartz content varies. From measurements of seismic velocities we can note that the bulk modulus of the various rock types varies by up to a factor of three.

On the small scale, high modulus rock is the worst for strain bursting, especially when it is close to and interleafed with lower modulus rock. This was particularly well illustrated in a recent small burst, when a lens of porphry surrounded by syenite burst in a development end. Likewise, on the larger scale, areas of high modulus rock are very much more likely to burst on a stope size scale, or even several stopes in size.

Our effort has been directed to the measurement of rock seismic velocities in the mine, thereby obtaining a measure of bulk modulus or the variation of bulk modulus. This work is done using a six-channel seisometer activated by either hammer blows in a stope or on a level and geophones on the level above. Using this system the seismic velocity of each path is measured and in effect we are undertaking mapping of the bulk modulus. The results of this correlate very well with detailed geological mapping. Using this idea we hope to outline and identify areas where there are potential rockburst problems. In areas of indicated high rockburst potential, extra support precautions can be taken. Damage can always be reduced by better support.

The study of modulus measurements has included investigation of destressing. Destressing is a technique that has been used extensively in North America for many years. It appears to give some relief. However, work in South Africa has indicated that there is no theoretical reason why this technique should work. In our opinion destressing is a misnomer as, in effect, the rock is softened. At Macassa we have measured this effect. Seismic velocity measurements before and after destressing show significant differences with a reduction in velocity, and thus a reduction in modulus after destressing. However, it should be noted that this reduction in velocity has been accomplished without any visible fracturing. Our work in this field is at a very early stage, however, we feel that rock softening can be achieved in areas where there is an indicated high potential rockburst problem. This softening will promote micro-fracturing but not real fracturing and when the softened rock is stressed it will fail peacefully and not explosively. Peaceful failure merely leads to a ground support problem that is relatively easy to combat.

In the past we have considered the possibility of installing microseismic or seismic monitoring systems. However, we considered it not the best value for an investment dollar. In our opinion, in early rock mechanics research in South Africa, this monitoring of seismic events was a useful data collection exercise but since there are as yet no indications that prewarning of bursts can be given by such a system, monitoring for the sake of monitoring does not appear to be a useful exercise.

A rock stress monitor by McPhar was tested at Macassa for about four weeks, but nothing useful became of that exercise. In situ stresses are currently being measured via the good offices of CANMET and the results of the first two tests on the 64 level, which were approximately 6400 ft below surface, are as follows:

Vertical stress	6 600 psi
Horizontal north/south stress normal to the orebody	11 500 psi
i.e., K = 1.7	
Horizontal east/west stresses parallel to the orebody	8 200 psi
i.e., K = 1.2	

These measurements largely confirm original guesstimates although the horizontal north/south stress is slightly higher.

The results of this stress measuring will be used to refine the modelling that was done to calculate the size of a shaft pillar or the new shaft pillar.

With our present knowledge we feel that it will be possible to identify rockburst prone areas and once we have done that we can do something about controlling them. However, we are not in any sort of position to predict bursts with instruments, either with microseismic or ultrasonic techniques. If there is to be any predictive tool in the future it seems that a whole new type of instrumentation is required.

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MONITORING HIGHLY STRESSED ROCK MASSES IN A ROCKBURST PRONE MINE

J. Bourbonnais
Roctest Ltd.

ABSTRACT

During 1978 and 1979, Rocktest Ltd., under contract to the Ministry of Energy and Resources of the Province of Quebec, undertook a general research study of rockburst phenomena in a deep underground mine. The East Malartic Mine, which is located in Northwestern Quebec, was chosen for this study because rockbursting activity had become an important concern in this area as far back as 1965. This paper describes the various types of measurement and monitoring programs used, and discusses their relative merits.

SURVEILLANCE DE MASSES ROCHEUSES SOUMISES À DE FORTES CONTRAINTES DANS UNE MINE SUJETTE AUX COUPS DE CHARGE

J. Bourbonnais
Roctest Ltée

RÉSUMÉ

En 1978 et 1979, la Roctest Ltée a entrepris, aux termes d'un contrat passé avec le ministère de l'Énergie et des Ressources du Québec, une étude générale de recherche sur les coups de charge dans une mine profonde. La mine East Malartic, située dans le nord-ouest du Québec, a été choisie pour cette étude car les coups de charge avaient commencé à créer des problèmes importants dans cette région dès 1965. La présente communication décrit les divers types de programmes de mesure et de surveillance utilisés et examine leurs avantages relatifs.

MONITORING HIGHLY STRESSED ROCK MASSES IN A ROCKBURST PRONE MINE

INTRODUCTION

The results presented herein are part of a general research study on rockbursting in deep mines conducted by Roctest Ltd. in 1978 and 1979 under contract with the Ministry of Energy and Resources of the Province of Quebec. The Centre de Recherches Minérales of the Ministry has kindly accepted the first-time presentation of some of the results obtained in the course of that study to this Workshop on Microseismic Monitoring in Canadian Mines.

Although general in scope, the study referred to above included field trials of a number of monitoring techniques showing some potential to locate highly stressed zones induced by mining. The techniques investigated are:

— Sound velocity measurement
— Measurement of stress changes by vibrating wire stress cells (VWSC)
— Microseismic monitoring

The measurement of in situ stresses with an overcoring technique was also performed to assess the local conditions at depth in a rockburst prone mine. The East Malartic Mine located in Northwestern Quebec was chosen for the undertaking of the field program. The support provided by the mine management and underground staff is acknowledged.

This communication will shortly cover the different techniques used, drawing some conclusions as to their capacity to identify highly stressed rock masses in a rockbursting environment.

SIMPLIFIED GEOLOGY AT THE MINE SITE

The geology at the mine site has been controlled by a major fault structure, known as the Malartic break, extending for several tens of miles on both sides of the area in the east-south-east direction. A plan view of the local geology is shown on Fig. 12.1. Eatins (1962) gives a detailed account of the geology.

The four major events that have characterized the evolution of the geology at the site are, in chronological order, from oldest to youngest:

i) The intrusion of a large mass of peridotite along the break;
ii) The formation of a talc-chlorite schist envelope around the peridotite, following numerous movements along the fault;
iii) The intrusion of small dioritic masses within the weak envelope;
iv) The intrusion of porphyritic masses through the same weak passage.

The East Malartic Mine lies along the southern limit of the peridotite intrusion. The orebody is divided into two zones: the main ore zone and the east ore zone shown on Fig. 12.1. It generally dips at 65 to 75 to the south.

A major geological difference exists between the two ore zones. Whereas the main ore zone rests against the talc-chlorite schists, the east ore zone, from about the eighth level down, lies against the massive porphyritic intrusion shown on Fig. 12.1.

HISTORY OF ROCKBURSTING

From 1965 rockbursting activity started being important at the East Malartic Mine. Figure 12.2 shows a longitudinal section of the mine indicating the location of the zones damaged by bursts in the period 1965 to 1979.

The figure shows that the located damages are mostly concentrated in the east ore zone. Geology is readily identified as an important cause of bursting because of the presence of the highly brittle porphyry rock in the east ore zone.

The mining plans for 1978 and 1979 showed development work and stoping activity to be mainly concentrated below level 31, especially in stope 32-64 shown on Fig. 12.2. This area was of major interest in undertaking the monitoring program, being at great depth as well as within the burst prone porphyritic intrusion.

IN SITU STRESS MEASUREMENT

The measurement of the in situ stress tensor was done by the doorstopper overcoring technique in three boreholes. It was intended to determine the tensor as far as possible outside the mined out area but the location of the site was finally controlled by the extent of the air and water lines. The test site was located on level 31 at section 6750 (see Fig. 12.2).

The results calculated from the strain reliefs recorded are plotted in the lower hemisphere of the equal area net shown on Fig. 12.3. They are based on a value of Poisson's ratio of 0.3 and a Young's modulus of 70 GPa determined with the borehole simulator device.

The calulcations gave a value of 83.1 MPa (12 050 psi) for the major principal stress which is practically acting in the horizontal plane with a slight plunge of two degrees in the S12°W direction. This direction, given with respect to the mine north, is approximately perpendicular to the orebody. The other two principal stresses were found to be almost equal. The intermediate took a value of 74.0 MPa (10 740 psi) and the minor principal stress, a value of 69.6 MPa (10 090 psi).

The stress tensor gave a value of the vertical stress of 71.9 MPa (10 430 psi) which is approximately 1.75 times higher than the overburden stress calculated for level 31. This situation is unusual, based on results obtained worldwide and documented by Herget et al (1975), and is thought to be due to the important stress transfer to the eastern abutment of the mine caused by extensive caving in the east ore zone (Fig. 12.2).

SOUND VELOCITY MEASUREMENT

Prior to this research project, the measurement of sound velocity through rock had been undertaken at Galena mine in the Coeur d'Alène district of Idaho. Blake et al (1974) had indicated its potential with respect to locating, mapping and evaluating areas of increasing or decreasing stress.

A velocity survey was undertaken prior to mining in stope 32-64 to test the potential of the method. A 12-channel Abem Trio seismic system was used. Triggering was obtained with a sledge hammer equipped with a mercury switch.

Figure 12.4 shows the seismic velocity results. Velocity paths go from the sill drift to the first sublevel and from the latter to the third sublevel. The velocities shown are in thousands of feet per second and as the figure shows, they are very high ranging from 6.1 km/sec (20 000 ft/sec) to 7.6 km/sec (25 000 ft/sec).

This result proved very interesting in view of the fact that previous laboratory results on rock samples of different types had shown that sound velocity through rock cannot go much higher than the limit reached in stope 32-64, and this under any stress state (Volarovich et al, 1963; Thill, 1972). In the case of stope 32-64, there were no indications of impending instability that could be related to the high velocities measured.

Recent results published by Gladwin (1982) confirmed the conclusions arrived at in the course of the research project. Figures 12.5a and 12.5b are taken from his publication. Figure 12.5a shows how typically the compressional wave velocity varies with hydrostatic pressure in different rock types. The velocity variation is initially quite important for the first 50 to 75 MPa (7250 to 10 900 psi) but, beyond that stress level, very little change in velocity is observed.

Figure 12.5b is a translation of Fig. 12.5a into a sensitivity parameter given in metre/sec/MPa. This sensitivity is relatively high at low stresses, but drops rapidly for all rock types at stresses above 75 MPa (10 900 psi). A sensitivity of 1 m/sec/MPa is typical, which means that for a stress change from 70 to 140 MPa (10 150 to 20 300 psi) a velocity variation of about 70 m/sec must be resolved. Obviously this situation imposes major constraints on the equipment and technique used if velocity monitoring is to provide useful information on stress conditions.

To summarize, the following conclusions are drawn on the use of sound velocity measurement in underground mining:

1. The sensitivity of the technique decreases markedly with depth.
2. The method can help locate a highly stressed zone provided access is possible on both sides of that zone. The significance of identifying such a zone will be much higher at shallow than at large depth.
3. The method cannot easily define the nature of the stress field acting on a rock mass that is hydrostatic or deviatoric.
4. A high velocity does not necessarily mean imminent instability.
5. In an initially stable highly stressed zone ($\sigma_{ij} \cong 70$ MPa), it is practically impossible to detect a stress increase without the use of sophisticated equipment. The measurement of a stress decrease through a velocity decrease is much more feasible. This latter case applies well to the evaluation of destressing experiments.

STRESS CHANGE MEASUREMENT WITH VIBRATING WIRE STRESS CELLS

The high initial stresses measured on level 31 and the important rock bursting activity known to have occurred at the East Malartic Mine justified the trial of a technique capable of measuring important stress changes induced by mining. It was thought such a technique could potentially be used to follow and qualify stress variations in a rock mass likely to be the focus of a rockburst.

The uniaxial vibrating wire stress cell was used in the lower part of stope 32-64. The hard-rock cell has a stress change measuring range of 70 MPa and can be prestressed so that increases or decreases in stress can be recorded.

Figure 12.6 is a plan view at the level of the sill drift showing the location of the 23 stress cells used. For the most part, these cells were installed in the vertical direction, in porphyry, north of the contact with the greywacke, within rock bodies defined by drawpoints 1 to 5. Four groups of cells are identified on Fig. 12.6.

Measurements were taken from the start of mining for a period of approximately seven months. Although mining was continuing at that time, reading of the cells had to be abandonned due to the intense deterioration of the drawpoints and, in a large number of cases, the impossible access to the wire leads connected to the cells due to their burial by the broken ore.

The analysis of the results obtained with the vibrating wire stress cells led to the following conclusions:

1. The satisfactory working of the cells over the monitoring period proves their reliability when installed in highly stressed rock.
2. The closely spaced cells installed in the highly stressed pillars defined by the drawpoints show qualitatively the same mode of variation of the stress but at the same time, important differences in magnitude. These differences are indicative of the fractured state of the pillars which develops with mining.
3. In a rockburst prone environment, one cannot anticipate monitoring adequately the behaviour of a large rock mass with stress cells unless a great quantity is used. The cost of doing so would certainly be prohibitive. Nevertheless, stress cells can find an application in evaluating the behaviour of a well defined specific rock body.

MICROSEISMIC MONITORING

Since the early seventies, much effort had been devoted, particularly in the United States, to the development and implementation of multichannel microseismic monitoring in rockburst prone mines. Some Canadian work had been done on single-channel monitoring but experience was non-existent with systems that allowed source location of a microseismic event.

In order to prove the potential of the technique, it was decided to install a 16-channel 250 MP microseismic system that provided the basic arrival time information. Further processing of the data was done subsequently. A description of the system and a detailed account of the microseismic activity recorded during this research project are presented by Bourbonnais (1981).

The installation and operation of the microseismic system at the East Malartic Mine were done under particular circumstances. Indeed, the perspective of closure of the mine was always present throughout the project. Installation was completed in less than two weeks, after laying approximately 7600 m (25 000 ft) of electrical cables. The mine operator decided to close the mine less than two months after the switching on the system. Nevertheless, some valuable data was recorded. A high level of microseismic activity was monitored and four major rockbursts have occurred.

Figure 12.7 shows the daily rate of emission of all microseismic events recorded throughout the monitoring period. All mining operations had been stopped at the end of September 1979 so that monitoring was done in a quiet environment until November 11. This situation explains the gradual decay of the microseismic activity shown on Fig. 12.7.

During the monitoring period, more than 1600 events were recorded and two large rockbursts and a smaller one occurred. A third and a fourth rockburst, both of large magnitude, took place on November 14 and 21 within nine days of switching off the system.

Source location was done either with the direct method or the least square method as documented by Blake et al (1974). The source coordinates calculated were systematically compared to a theoretical solution obtained by the Generated Block Method (Blake et al, 1974) and accepted or rejected depending on the correspondence. Performing this tedious work showed that the best correspondence was in most instances obtained with the direct method, using a minimum number of arrival times.

The conclusion arrived at above was substantiated by test blasts inside and outside the geophone array, which clearly showed the influence of delayed triggering on the source locations calculated. Open stopes and extensive caving in the east ore zone, and the overall looseness of the mass resulting from frequent rockbursting, constitute important causes of delayed triggering.

Microseismic events located with a high level of confidence are shown on Fig. 12.8. They represent a proportion of 50% of all events recorded. The figure also shows the position of the 16 geophones spread out between levels 27 and 32 and the location of the eight test blasts numbered 1 to 8.

Within the array, test blasts 1 to 4 showed that it was possible to locate within approximately 35 metres. Outside the array, the location was impossible for test blasts 5 to 7. However, test blast 8 fired at a distance of over 320 m from level 29, could be located within 60 m with the direct method. Even though far outside the array, this test blast could be fairly well located because the sound wave propagated through a relatively continuous mass and was picked up by a sufficient number of geophones. This indicates the importance of good geophone location planning prior to laying the array.

The events located and shown on Fig. 12.8 helped develop an evaluation of the area monitored during less than two months. It is seen that:

1. A large proportion of the events was located between level 27 and 31, between shaft No. 5 and the mill-hole 31-52. The density is particularly high between levels 27 and 29 and is thought to be related to the progression of the cave line above stopes 31-50S and 31-50N.
   The proximity of the geological contact between the talc-chlorite schists and the prophyry intrusive favoured the development and violent release of energy. The four major rockbursts shown on Fig. 12.9 appear interrelated, as covered by Bourbonnais (1981), and are probably the result of the continuous readjustment of the stresses caused by the likely progressive caving mentioned above.

2. The events located above stope 31-62 define relatively closely the approximate limits of the cave line determined by the mine personnel.
3. Some activity is concentrated around shaft No. 5 and could be the sign of a deteriorating condition.
4. Stope 32-64, mined in the course of this project, is the site of some concentrated events at its western face and within the crown pillar. Because of the unfavorable geometry developing, these events are indicators of potential bursting.

These features representing the on-going condition of the lower part of the east ore zone during the monitoring period constitute an important data base to understand the relationship between the mining variables in this rockburst prone environment. Although the East Malartic Mine closed shortly after this project, no doubt the simple recognition that rockbursting tended to follow the geological contact could have helped implement some measures, such as increased localized support, that could have decreased the level of risk associated with bursting. Further monitoring could have helped prove if, indeed, the heavy bursting recorded was directly related to the progressive caving just west of the geological contact, and could thus have led to another set of actions to diminish or even perhaps eliminate the rockburst probability of occurrence.

CONCLUSION

The results presented in this paper were obtained in the course of a research study on rockbursting in deep mines conducted by Roctest Ltd. in the years 1978 and 1979, under contract with the Ministry of Energy and Resources of the Province of Quebec. The field work undertaken at the East Malartic Mine, known for its rockbursting activity, aimed at investigating different techniques showing potential to locate and monitor the evolution of highly stressed zones induced by mining. The techniques investigated are:

— the sound velocity measurement;
— the measurement of stress changes by vibrating wire stress cells;
— microseismic monitoring.

In situ stresses were also determined at a depth of 1475 m below surface. The major principal stress was found to be horizontal, approximately perpendicular to the east-west trending orebody and twice as large as the calculated overburden stress for that depth. The vertical component of the stress tensor proved to be 1.75 times larger than the calculated overburden stress and this was attributed to the important stress transfer to the eastern abutment of the mine, caused by extensive caving in the east ore zone.

The evaluation of the different techniques studied showed that seismic surveys and stress change measurements are more suited to monitoring the behaviour of specific rock bodies once they have been identified as sites for likely important stress changes. In already highly stressed rock, sound velocity measurements will detect stress decreases much more easily than stress increases.

The microseismic technique is unique in that it can cover with the same efficiency an extensive area of a mine, locate zones of stress build-up and allow their subsequent evaluation. Although its success as a predictive tool has been rather slim, it is believed that provided the analysis of the microseismic activity is done systematically and periodically it can greatly help understand the relationship between the mining variables and from there improve on design. The amount of information gained in only one month and a half of monitoring at the East Malartic Mine supports this view.

ACKNOWLEDGEMENTS

The author would like to thank the management of East Malartic Mines Ltd. for their constant support during this project and the Centre de Recherches Minérales of the Ministry of Energy and Resources of Quebec for their permission to publish some results obtained during the research project. The work of Mr. Paul Rochon, rock mechanics engineer, presently with the Service de Technologie Minière of the same Ministry is also greatly appreciated.

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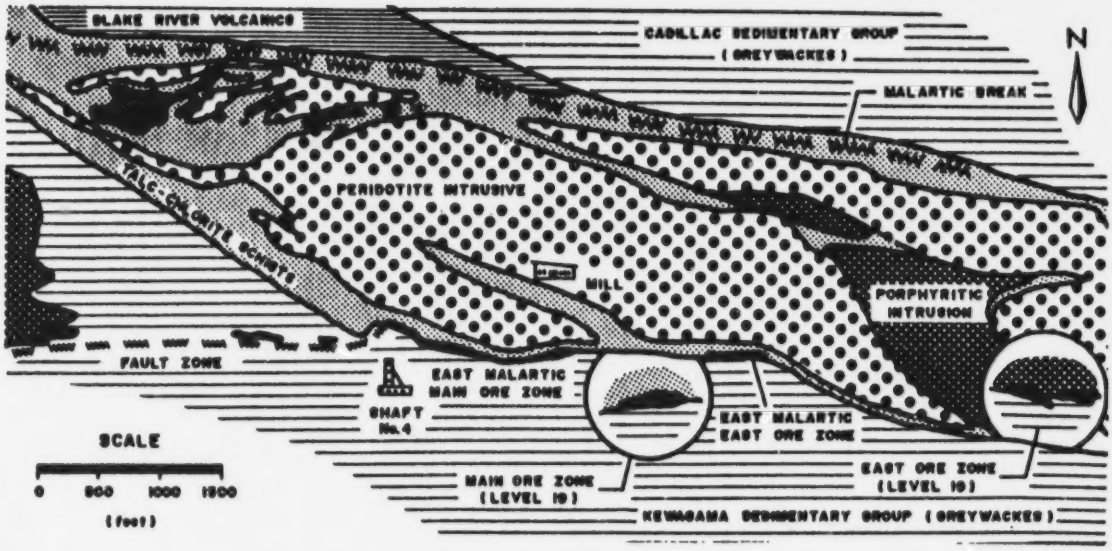

Fig. 12.1 — Plan view of local geology

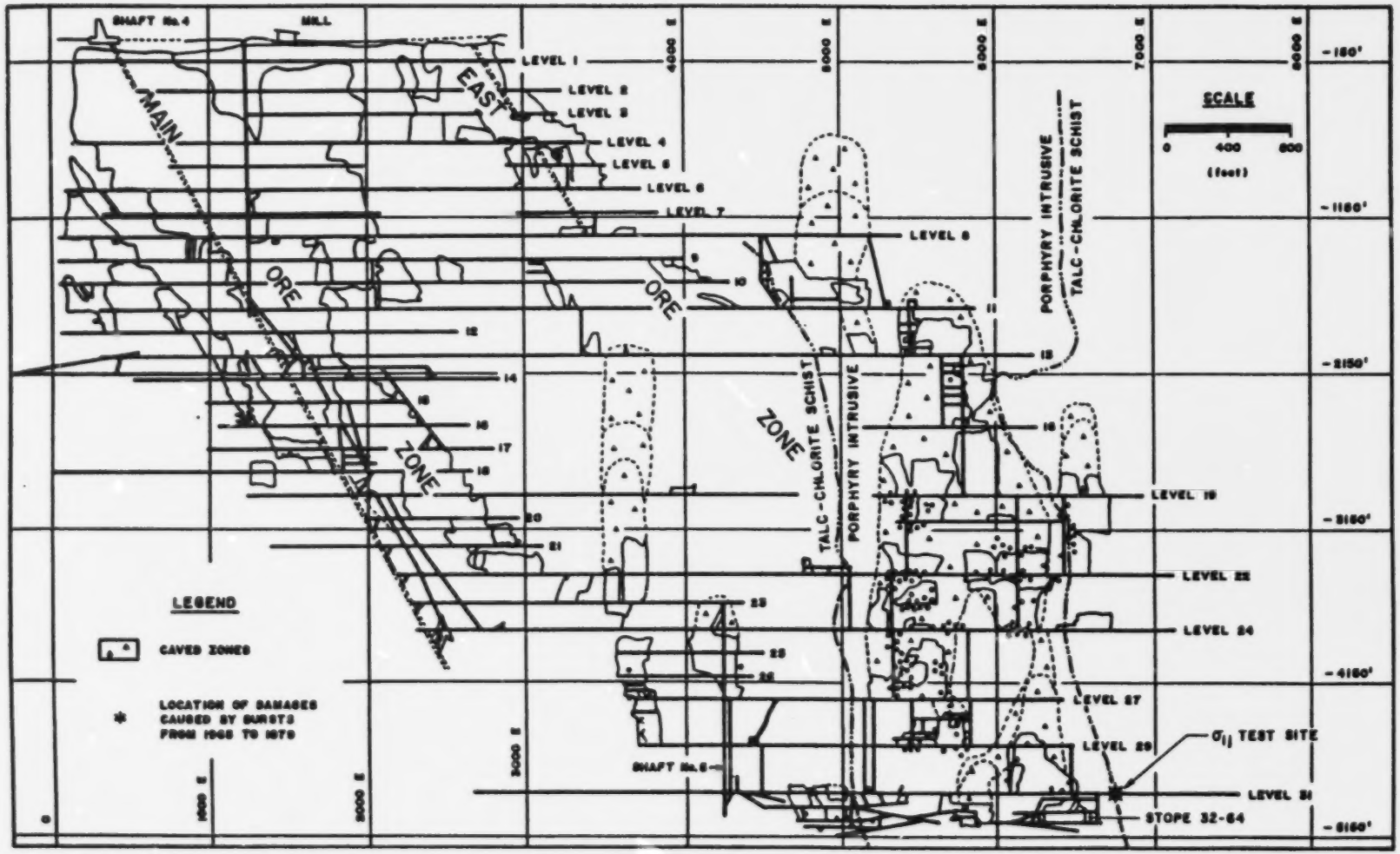

Fig. 12.2 — Location of damages caused by rockbursts from 1965 to 1979

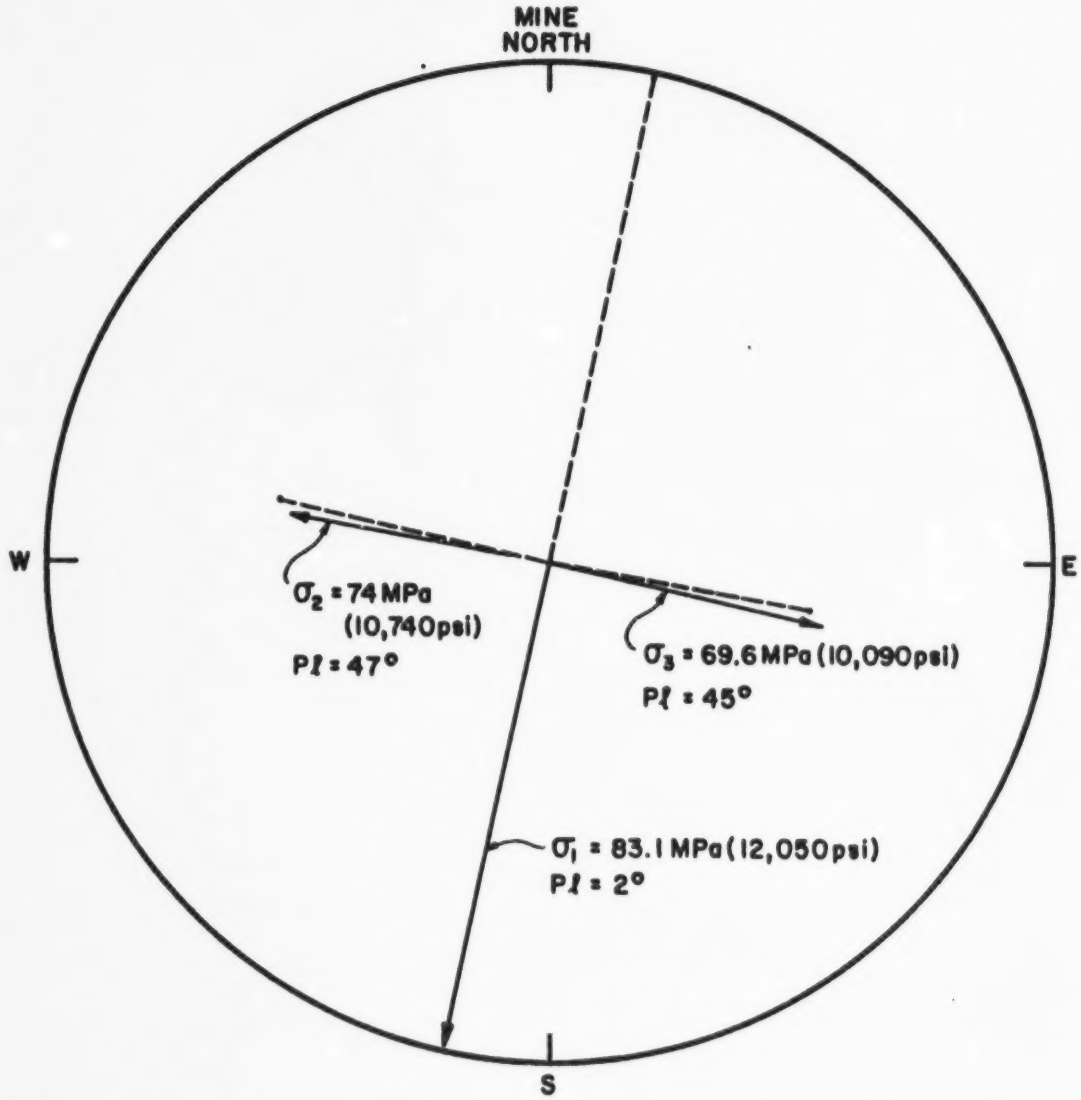

Fig. 12.3 — East Malartic Mine, level 31, in situ principal stress plot in lower hemisphere of equal area net

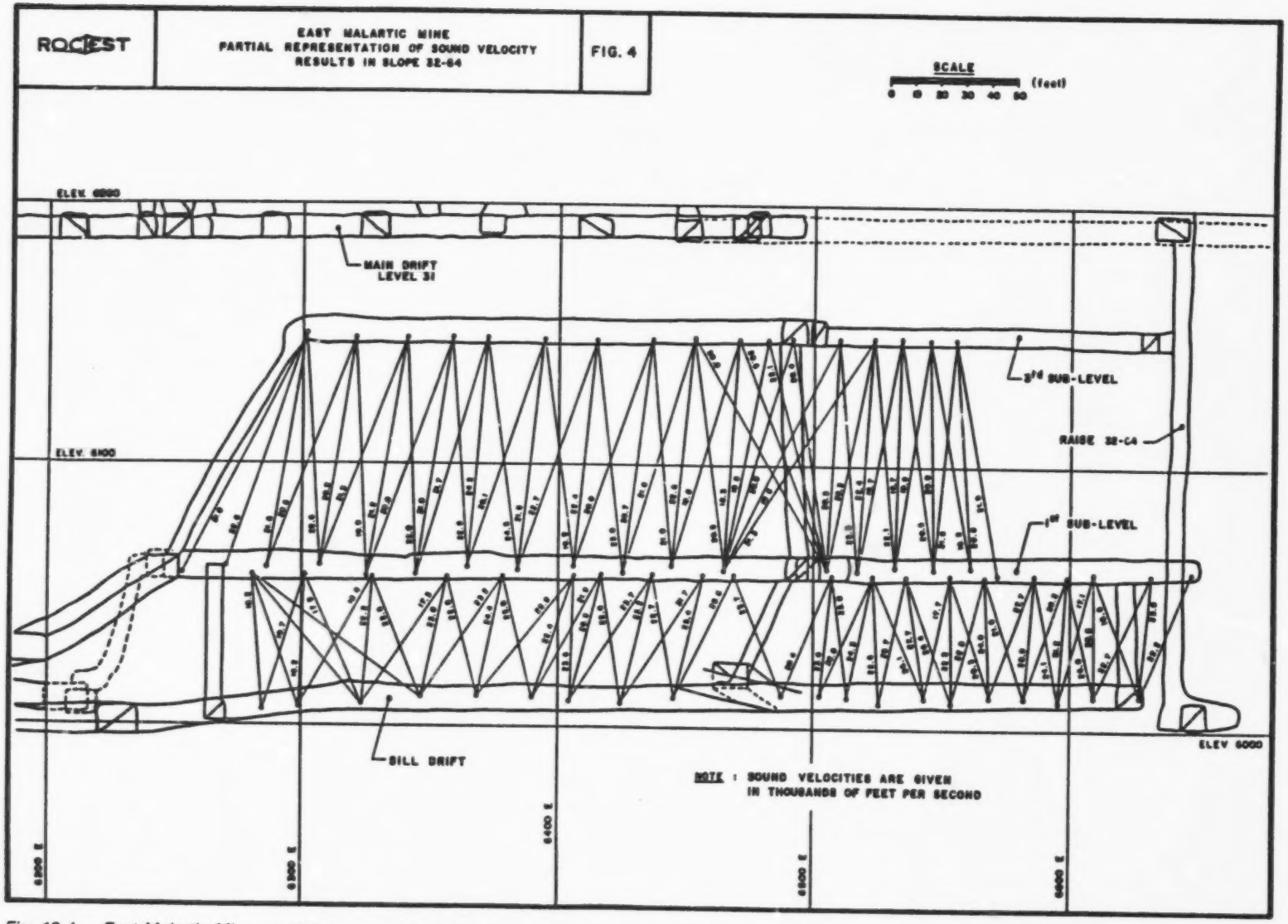

Fig. 12.4 — East Malartic Mine. partial representation of sound velocity results in stope 32-64

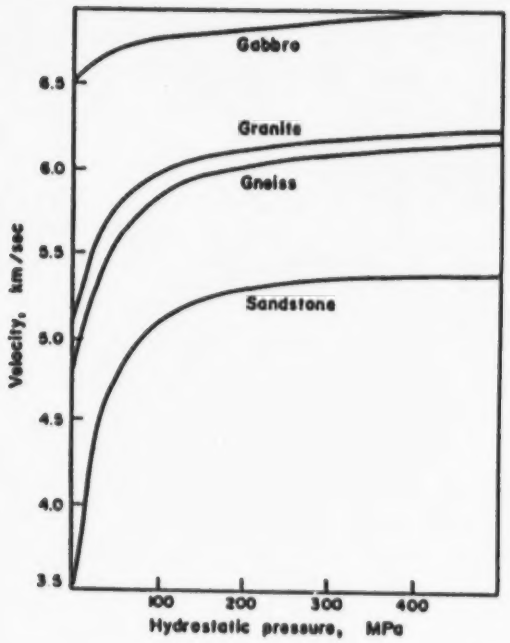

Fig. 12.5a — Typical compressional wave velocity variation with hydrostatic pressure

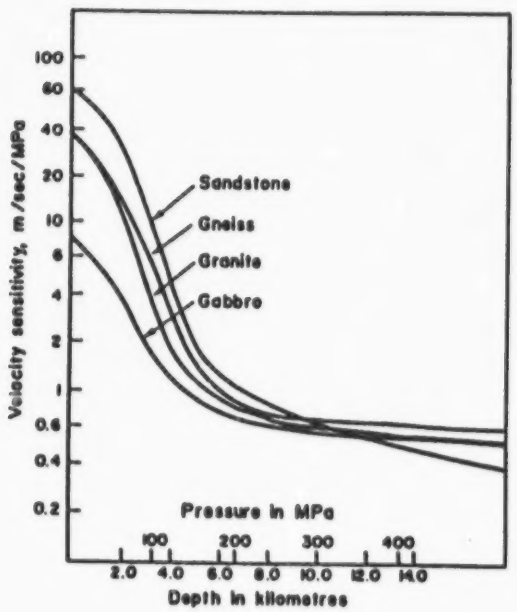

Fig. 12.5b — Variation with confining pressure of velocity sensitivity (m per sec per MPa) for intact samples. In the mining environment ambient stress levels less than 100 MPa are expected

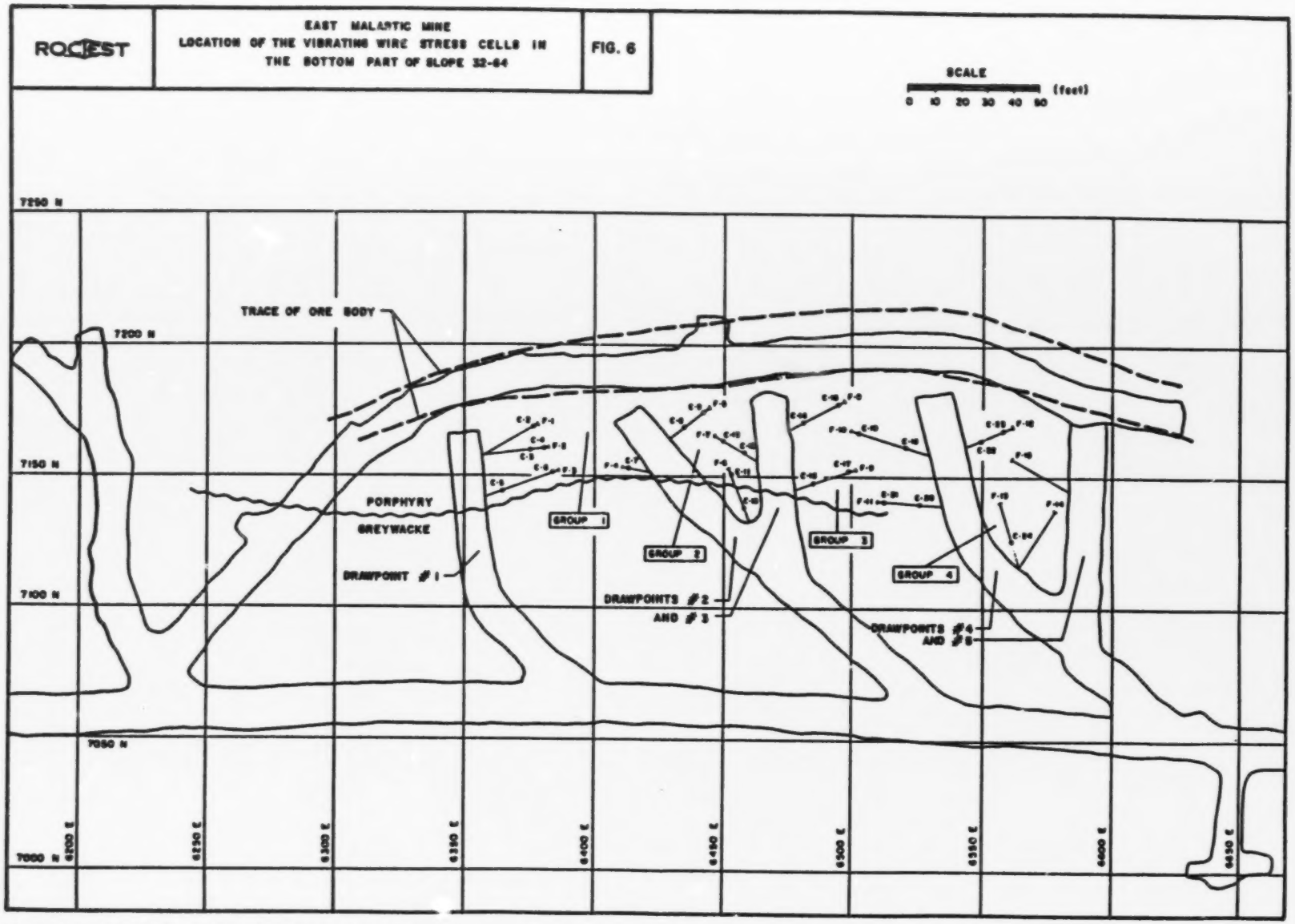

Fig. 12.6 — East Malartic Mine, location of the vibrating wire stress cells in the bottom part of slope 32-64

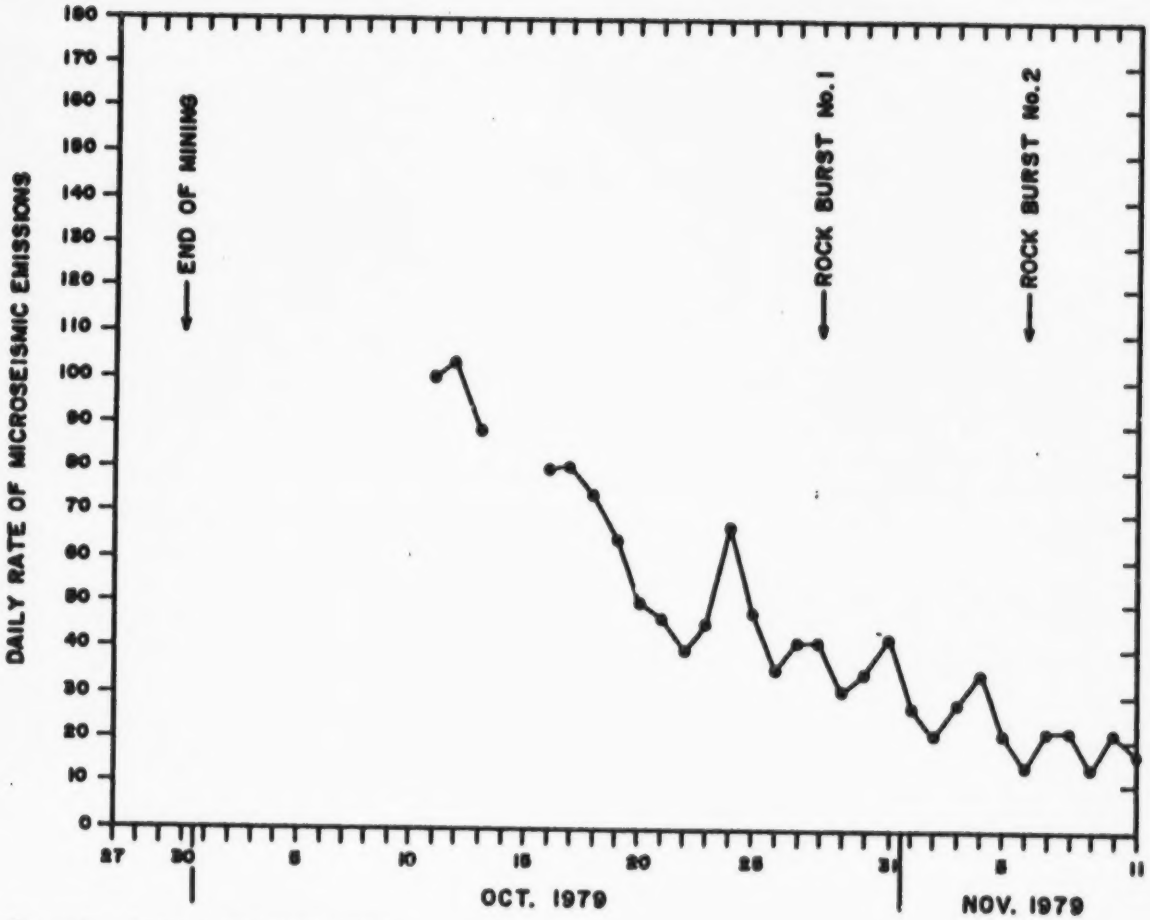

Fig. 12.7 — Decay of the seismic activity

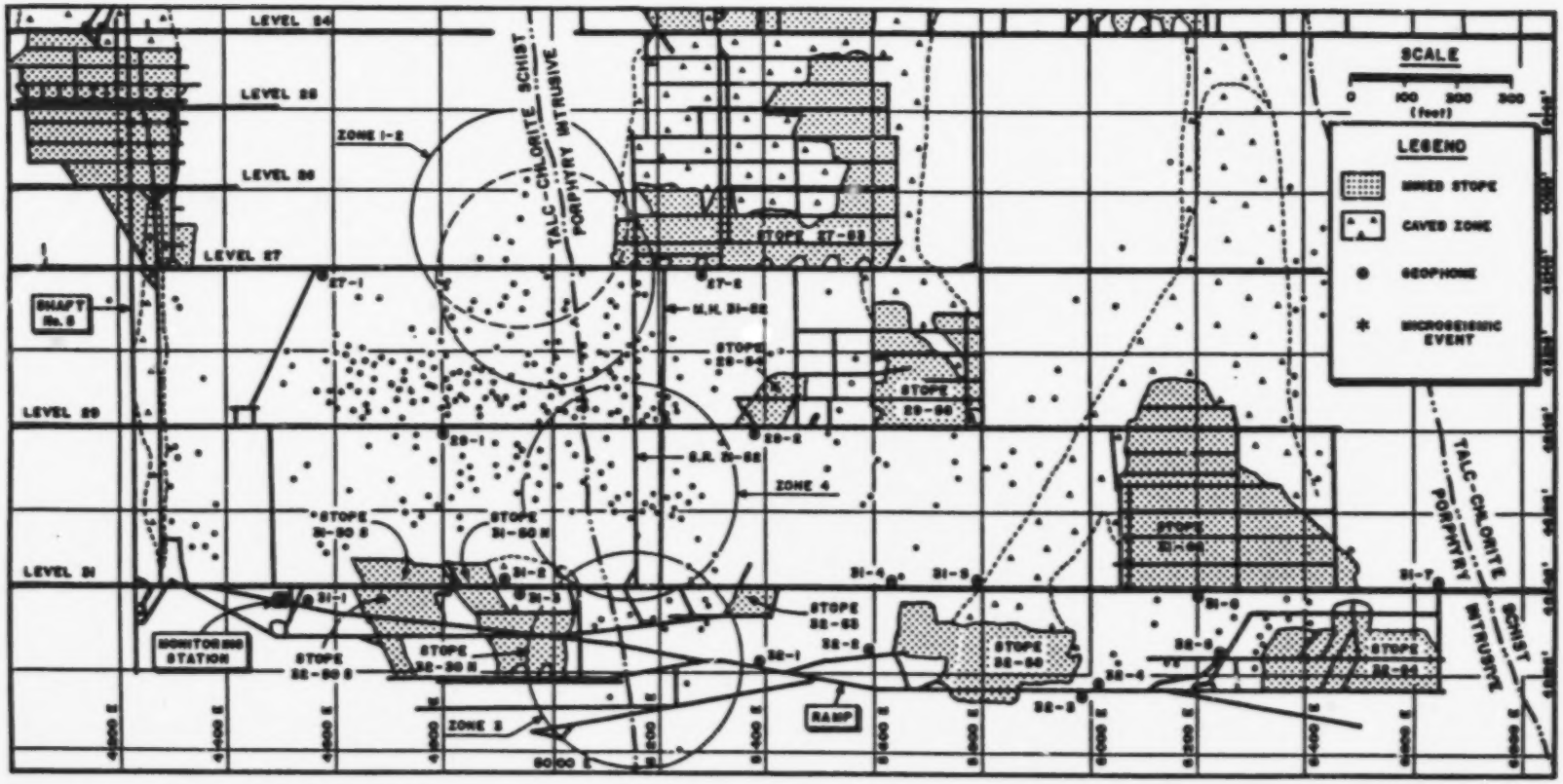

Fig. 12.8 — East Malartic Mine, location of microseismic events recorded from September 25 to November 12, 1979

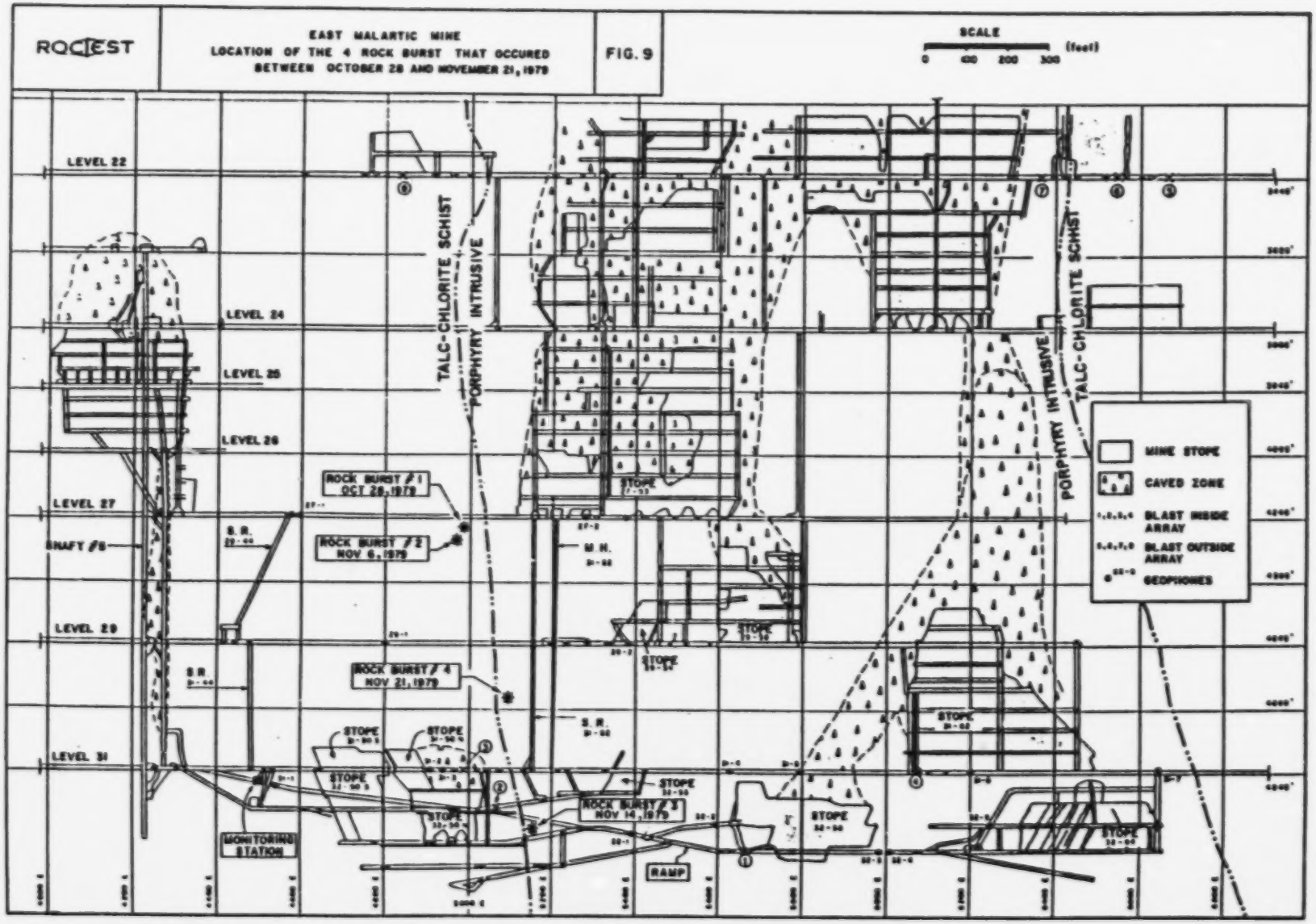

Fig. 12.9 — East Malartic Mine, location of the four rockbursts that occurred between October 28 and November 21, 1979

DISCUSSION

P. MacDonald: Are there many documented examples of major seismic events being preceded by trends in microseismic activity?

P. Oliver: A couple of examples at INCO. An increase in audible events occurred prior to a major pillar failure. For approximately a week there was a build-up in activity. The men were withdrawn and a large rockburst occurred. In another case, as soon as seismicity developed, so did pillar failure. These are general warnings, rather than specific recorded patterns.

T. Makuch: At Campbell we listened to one geophone every morning and heard a lot of snapping and cracking. None of the events was large enough to trigger five geophones. The underground supervisors were informed and the men kept out of the area. 2-1/4 h after the warning was given underground, a rockburst occurred just on the other side of the party wall in Dickenson.

We also use a portable accelerometer-based unit to monitor the activity in localized zones. This allows monitoring of events that are not large enough to trigger five geophones.

H. Miller: With rockbursts occurring in all different types of mines throughout the world, it must be worthwhile to study all the factors involved. By the use of modelling and testing it will then be possible to assess the likelihood of rockbursts occurring in specific mining areas. It may be more fruitful to look at the rockburst problem from the point of view of the mechanisms, and evaluating the potential for bursting rather than attempting to reliably predict rockbursts using instrumentation.

S. Bharti: We found that much of the emphasis in South Africa is to tell where an event has taken place, using microseismic monitoring. They seem prepared to leave pillars now to reduce the likelihood of rockbursts.

C. Page: South African research has led to the Energy Release Rate for use in their specific mining situation. You have to take each mining situation and build up calibration data for the modelling system to be used.

P. Oliver: We have problems associated with irregular orebodies when modelling. This leads to problems with calibration between the extremes of stability on one hand and problem areas on the other, which may tend to burst or just yield. Microseismic monitoring may assist us here, identifying which geometries will burst and which will yield.

J. Vance: In terms of giving warning of rockbursts, microseismic monitoring is used in the Coeur D'Alène to the extent that at Galena Mine only certain areas are worked when the USBM operator is on site.

C. Malott: It is only by using very dense arrays, as for instance at Galena, and detecting true microseismic activity, that it is likely that rockbursts could be predicted. However, at Galena only a small part of the mine is covered with any sort of array.

P. MacDonald: In summary, there are very few cases where locatable events have been used to give warning of rockbursts, and men have been taken out of working places. Rather it is found that cracking and snapping on an individual geophone is followed, within a day or week, by a major event in the area. The objective of the question was to see if an approach could be made to rockburst prediction. If extremely dense arrays are required, the strategy may require rethinking on economic or technical grounds.

B. Smith: How valid is point-source location when events are of a fault-slip type?

H. Miller: In South Africa, it was found that dissipation of energy could have originated at a focus associated with fault movement. It would, therefore, be better to think of a combination of point source and fault slip occurring sometimes, rather than simply the individual types.

C. Page: In South Africa, I think all rockbursts originate on a planar feature. What is seen is where the energy release causes dislocation of rock from the walls.

J. Vance: One thing that has been noted recently is that a series of seismic events at Cory Mine have tended to form a spatial concentration, rather than increasing in frequency with time. The events have been located over a recently-completed panel. Therefore, treating the events in terms of space, rather than time, may give patterns that aren't obvious so far.

C. Malott: (in response to questions about the Electro Lab source location algorithm). The solution of the source location will be changed. The present determination is based on Blake and Leighton's linear equation direct solution method. The new version will use this as a first estimate of the location and conduct an iterative technique down to a solution that best fits the arrival time (which the current method doesn't do).

P. MacDonald: How often do seismic events occur in mines in areas where, from local experience, they wouldn't be expected?

D. West: One example is at Falconbridge No. 5 Mine, where prior to installation of the microseismic system, the hanging wall jasperoid lenses were consistently blasted in order to destress them. It was only when the system located the events in the footwall norites that it was realized that the lenses were not the cause of the seismic events.

J. Vance: With the surface and underground monitoring systems, events at Cory Mine were found to be occurring in the overlying limestones. Before monitoring, the locations of the events were complely unknown.

H. Miller: Events occurring way out in the solid at Western Deep Levels were explained by accurate source location. A fault could perhaps have been lined up with the source and this was of great interest to us. These events were only a small minority though, and without a doubt we knew the 'hot spots' in the mine. By using a microseismic source location system we had the data to back up arguments for different mining layouts. This was done in combination with modelling and we arrived at methods that reduced the number of rockbursts.

F. Ingham: At Quirke Mine we weren't, in general, surprised at any of the event locations. However, when events began to be located further up-dip of the existing area, minor signs of spalling were then seen. Major cracking and roof-falls did not occur until three months after seismic events indicated that the area was expanding up-dip.

P. MacDonald: Some people have no confidence in microseismic monitoring, as it doesn't predict events. However, I gather from the presentations here that the companies using microseismic monitoring have got different things out of the technique, nevertheless they are of great value to those companies. While events are not predicted at the moment, the technique has led to increased knowledge of the effects of mining on the rock mass. I hope that this meeting has broadened people's perspectives on the different benefits that the systems have brought. Also to understand, perhaps, the limitations of microseismic monitoring and how far we are from predicting rockbursts. There are, though, many different avenues to be pursued towards this final goal.

* * *

CONCLUDING REMARKS

J. Udd

First, I would like to thank each one of you and your organizations for the contributions to this workshop. This has been the first of its kind and, I hope, it will be the first of a long series of technology transfer sessions to be organized by the Mining Research Laboratories at CANMET. A short while ago, another session on a different topic was also very well attended, in Sudbury, and we are very gratified by the response to this one and hope that you agree that a lot of useful information has been exchanged. This has been a very good sharing session.

Before attempting to summarize the information which has been presented during the past two days, I would first like to congratulate Paul MacDonald for the masterful organization of the workshop.

Secondly, Phil Oliver and INCO metals are to be thanked for their hospitality in organizing the underground visit this morning to see the microseismic system at the Creighton Mine. I think that it is generally appreciated that INCO has made a very extensive commitment to microseismic monitoring, and I have no doubt that today's visit only enhanced this appreciation.

It has been said on occasions that CANMET doesn't work with, or listen to, industry. I would like to rebut this observation by noting the number of times that it has been mentioned, at this workshop, that CANMET has been involved in microseismic monitoring. These mentions bear witness to the fact that we are deeply involved in working with industry, and, I can assure you, we are going to become much more so in the years to come. Microseismic monitoring is becoming a major area of interest for us, and I think that you can look forward to an increased interest and commitment from MRL on this. The mission of CANMET is to provide a supporting service for Canadian industry, and I would like to encourage you to ask us to assist you, if you feel that we can help.

In summary, there are three general conclusions that can be made from the many things that have been discussed at this workshop.

First, as regards the application of microseismic monitoring, I think that we must make it clear that we are not dealing with local monitoring, but rather with mine-wide monitoring systems. I think that we could probably agree that, for that application, the microseismic method is probably the only option open at present. Quite frankly, I cannot think of an alternative, and I feel confident that you will agree with that. At the same time, having been a practising ground control engineer, I would like to add the observation that we can never forget that personal monitoring of conditions has to play a very major role in whatever we do in terms of improving occupational health and safety. The microseismic system is a valuable and indispensible research tool, but it can never replace the kind of personal observations that must be made underground on a routine basis.

The second conclusion, I suggest, is that while we would agree that microseismic systems are probably most useful as a research tool, when trying to assess the effects of mining sequences and practices, at present the element of predictability is simply too ephemeral. It is just not practical to say that these systems can now be used for predictive purposes. There is no doubt that we want to improve mining safety, and that we want to improve predictability to the greatest extent possible, but the technology, the equipment and the gear is simply not available at the present time.

The third conclusion is that all are facing difficulties with the operation of monitoring systems, and are looking forward to improvements, especially in determining the locations of events and the estimates of the energies involved. We are looking to manufacturers in North America, and elsewhere, to try to develop the technology that will permit us to do this.

This has been a very good workshop, and it is hoped that we can all get back together again in the no-to-distant future. Many thanks indeed.

* * *

CONCLUSIONS

J. Udd

Avant toute chose, je voudrais vous remercier tous ainsi que vos organismes pour les contributions apportées à cet atelier. C'est le premier de ce genre et j'espère qu'il sera le premier d'une longue série de séances de transfert de technologie qui seront organisées par les laboratoires de recherche minière du CANMET. Il n'y a pas longtemps, un autre atelier traitant d'un autre sujet avait attiré beaucoup de monde à Sudbury. Nous somme réjouis que vous soyez venus nombreux et nous espérons que vous êtes d'accord qu'au cours de cet atelier il y a eu un grand nombre d'échanges d'informations utiles. L'atelier a été un excellent moyen de partage.

Avant d'essayer de résumer l'information donnée pendant ces deux derniers jours, je voudrais d'abord féliciter Paul McDonald pour l'organisation magistrale de l'atelier.

Je voudrais ensuite remercier Phil Oliver et l'INCO qui ont organisé la visite de ce matin pour observer le système microscopique de la mine Creighton. Nous savions que l'INCO s'intéressait considérablement à la surveillance microsismique; la visite de ce matin nous a permis d'apprécier ses réalisations.

Je me permets d'ajouter une pensée: on dit parfois que le CANMET ne coopère pas avec le secteur industriel ou ne l'écoute pas. Je voudrais réfuter cette observation en faisant remarquer le nombre de cas cités lors de cet atelier et auxquels le CANMET a pris part, dans le domaine de la surveillance microsismique. Ces cas attestent que nous travaillons intimement avec l'industrie et que nous le ferons encore plus dans l'avenir. La surveillance microsismique devient un domaine qui nous intéresse énormément; soyez certains que les LRM traduiront en engagements concrets cet intérêt accru. La mission du CANMET est de fournir un service d'appui à l'industrie canadienne, aussi n'hésitez pas à frapper à sa porte si vous croyez qu'il est en mesure de vous aider.

En bref, on peut tirer trois conclusions générales de tout ce qui a été dit.

La première concerne l'application de la surveillance microsismique; je pense qu'il y a lieu de préciser que nous songeons non pas à un système de surveillance localisé mais bien à des systèmes établis à la grandeur de la mine. Nous sommes probablement d'accord que pour cette application, la méthode microsismique est peut-être la seule option disponible actuellement. En toute franchise, je ne vois pas d'autre solution et je suis certain que vous êtes d'accord avec moi. J'ajoute néanmoins, en ma qualité d'ancien ingénieur de stabilisation du sol, qu'il ne faut jamais oublier que la surveillance personnelle des conditions doit jouer un rôle très important dans tout ce que nous faisons afin d'améliorer la santé et la sécurité au travail. Le système microsismique est un instrument de recherche précieux et indispensable, mais il ne peut jamais remplacer les observations personnelles que nous devons faire régulièrement dans le sous-sol.

Ma seconde conclusion est que les systèmes microsismiques sont probablement plus utiles en tant qu'outils de recherche qu'en tant que moyen d'évaluer les effets des méthodes et des pratiques d'exploitation. À l'heure actuelle, leur utilité comme instrument de prévision est tout simplement trop limitée et il serait bien téméraire d'affirmer qu'ils peuvent aujourd'hui servir à établir des prévisions. Il n'y a aucun doute que nous voulons améliorer la sécurité dans les mines et que nous désirons raffiner nos méthodes de prévision au plus haut point possible, mais la technologie, l'équipement et les appareils nous font défaut.

La troisième conclusion est que l'exploitation des systèmes de surveillance nous pose tous des difficultés et nous espérons des améliorations: particulièrement dans la détermination des lieux où se situent les agitations et l'évaluation des énergies en jeu. C'est donc vers les fabricants d'Amérique du Nord et d'ailleurs que nous nous tournons, dans l'espoir qu'ils sauront mettre au point la technologie qui nous permettra d'arriver à ce résultat.

L'atelier a été une réussite et nous espérons que nous pourrons tous nous réunir de nouveau dans un proche avenir. Merci encore.

* * *

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